THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Platform Thinking for Technology Management

Supporting Knowledge Reuse in Technology Development

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ABSTRACT

'Platform thinking' is a product development strategy for taking advantage of the opportunities for synergy among a set of products that share certain features. A specific development methodology is needed to efficiently synchronize the design and production of a set of products and both research and industry have been contributing substantially to the development of such methodology. However, a company may develop a wide range of products that for various reasons cannot share components, while still offering opportunities for synergy since they build upon the same technologies and know-how for their development and production. These shared assets cannot be leveraged among products using the same platform development methodology as for physical components and instead of leaving this opportunity for asset reuse to chance, this thesis explores how to systematically support platform thinking for technology development.

As part of this research, two case studies were conducted at a company that operates in the aerospace engine industry. The studies revealed barriers to the reuse of technologies, including (1) the difficulties of locating, transferring and deploying knowledge generated by previous development projects, (2) the uncertainty of forecasting which technologies to develop for future reuse and (3) the need for adapting technologies before introducing new applications.

Besides the empirical case studies, two additional contributions to the study of platform-based technology development are provided. The first contribution is a review of relevant literature existing in various research fields that approached technology reuse from a range of perspectives, including technology planning, engineering reuse and knowledge management. The second contribution is a proposed methodology for development using multiple levels of platform thinking, ranging from physical components to design concepts and technological knowledge. In the product-level of the platform, a range of possible configurations of parts, as well as a spectrum of acceptable design parameters for the parts included, have been prepared to make sure that multiple ways exist to derive products from the platform. For the technology-level, the methodology is supported by an internal software-based catalogue containing information on the technologies used within a corporation. A catalogue prototype was developed using Wiki software, which included basic information about technologies and links to existing reports and contact information to relevant experts within the company. While small-scale tests elicited positive reactions from intended users at the case company, further studies are necessary to validate the usefulness of the catalogue and address concerns raised during the tests regarding the security and validity of information held in highly accessible repositories, such as Wikis.

Keywords: technology management, technology development, platform thinking, knowledge reuse.

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I would especially like to thank industrial researcher and PhD Ulf Högman for laying the foundation for my studies, as well as for providing me the opportunity to become part of this research by supervising my Master's thesis and supporting me to continue my studies towards the PhD degree. Our many discussions have considerably increased my understanding of technology development. Also, I highly appreciate the support from his colleagues at Volvo Aero Corporation, who were exceptionally open during our interviews and provided us information and opinions of their work practices.

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Alingsås, Sweden, 2013

Daniel Corin Stig

APPENDED PUBLICATIONS

Paper A
Corin Stig, D., Högman, U., Bergsjö, D. (2011). Assessment of Readiness for Internal Technology Transfer – A Case Study. *Proceedings of the 21st Annual International Symposium of the International Council on Systems Engineering* (*INCOSE 2011)*, Denver, CO, USA, June 20-23, 2011.

Paper B
Corin Stig, D., Högman, U., Bergsjö, D. (2013). Improving Flexibility and Reuse for Technology Development. Accepted to: *Systems Research Forum*.

Paper C
Corin Stig, D., Bergsjö, D. (2011). Means for Internal Knowledge Reuse in Pre-Development – The Technology Platform Approach. *Proceedings of the 18th International Conference on Engineering Design (ICED 2011*), Copenhagen, Denmark, August 15-18, 2011.

Paper D
Levandowski, C., Corin Stig, D., Bergsjö, D., Forslund, A., Högman, U., Söderberg, R., Johannesson, H. (2013). An Integrated Approach to Technology Platform and Product Platform Development. Forthcoming in: *Concurrent Engineering – Research and Applications*, first published on December 12, 2012 as doi:10.1177/1063293X12467808.

DISTRIBUTION OF WORK

Paper A: Daniel Corin Stig planned the study, conducted the primary interviews for the study and performed the analysis with the support of Ulf Högman. Recordings of interviews conducted by Daniel Bengtsson and Stefan Stetz for their MSc thesis (2009) were used as additional sources of data. Daniel Corin Stig wrote the majority of the paper, with support and contributions from Ulf Högman and Dag Bergsjö.

Paper B: Daniel Corin Stig conducted the literature review and wrote the majority of the paper with the support of Dag Bergsjö. Ulf Högman wrote the section 'Characteristics of technology development' based on his own literature review.

Paper C: Daniel Corin Stig and Dag Bergsjö jointly planned the study, developed the software prototype, conducted the interviews, performed the analysis and wrote the paper.

Paper D: Christoffer Levandowski coordinated the project and wrote the paper together with Dag Bergsjö, Daniel Corin Stig, Anders Forslund and Ulf Högman. Christoffer Levandowski created the system architecture and set up the case together with Dag Bergsjö and Daniel Corin Stig. The planning, analysis and writing of the paper was supported by Rikard Söderberg and Hans Johannesson.

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1 INTRODUCTION

1.1 Background

Rapid and resource-efficient development of high quality products is the main success criterion for product development. With high volumes, the cost-per-unit for development and manufacturing of a product can normally be reduced through economies-of-scale. However, customer demand is seldom homogenous, meaning that multiple product variants are necessary for appealing to the diverse preferences of different market segments. A widespread solution to this paradox of high volumes and high customization is platform-based development. A product platform is “a set of subsystems and interfaces that form a common structure from which a stream of derivative products can be efficiently developed and produced” (Meyer and Lehnerd, 1997 p.39). Hence, the common structure attains the benefits of high volumes, while the remaining features of the products can be customized to offer the market a variety of models. While the most widely known platform strategy involves introducing modularization and common parts, the idea of sharing costly investments among products can be extended to also include technologies, production equipment, customer relations and product architectures. The process of identifying and exploiting similarities between products has been referred to as ‘platform thinking’ (Sawhney, 1998). This thesis focuses on how to apply this thinking to technology management.

Large organizations typically have the advantage of being able to leverage their competencies among many products and business areas, and find synergies among them. However, in an organization where competencies and skilled employees are in abundance, staying updated on the variety of available assets is difficult. Compared to a smaller company, a larger company faces the likelihood that developers will reinvent the work of someone else or miss opportunities to reuse existing superior solutions to solve design problems. The purpose of this thesis is to gain additional insight into the reasons why the above is occurring and what companies can do on an operational level to improve the (re-)usefulness of their acquired technological competencies.

This research project originates from an initiative started at Volvo Aero Corporation[1] (VAC) to improve the efficiency of its technology development projects. VAC develops and manufactures components and subsystems for aircraft engines, with the majority of its operations at the headquarters in Trollhättan, Sweden. VAC operates across three different business areas: space propulsion, military aircraft, and commercial aircraft, which were managed quite independently until a reorganization in 2003 when they became integrated. Its products are characterized by advanced technology and low volumes, and the strategy of VAC has been to focus on developing strong capabilities within a number of key technological areas and work with multiple engine makers as risk-and-revenue sharing partners. While their specialized competence can be leveraged across various products to different customers or partners, the reuse of the detailed designs is complicated by a number of factors (Högman et al., 2009). One factor is that designs developed in alliances may have elements that are the property-rights of their partners, which must not be reused

[1] VAC has since been acquired by GKN Aerospace

in products developed with other partners. Another factor is that in order to make components reusable in different products, trade-offs are required with regard to their design that make it impossible to meet expected high performance requirements. Instead, when industrial researcher Ulf Högman together with his colleagues analyzed the potential for reusing components using a product platform approach at VAC, they found that most of the assets shared between products consisted of technological knowledge (Berglund et al., 2008). However, they found few examples of research focusing on platform thinking for technology development. Technologies are different from products in a number of characteristics, suggesting that new types of support are needed for managing technologies with the help of a platform strategy. Additionally, technologies present opportunities for reusing assets across a more diverse set of products, which poses new challenges to synchronizing development efforts of projects or organizational units that have previously operated independently.

For further reading about VAC, an extensive description of the company and related research on its technology development processes are provided in the dissertation by Ulf Högman (2011). Throughout this thesis, VAC is often referred to as 'the case company'.

1.2 Research Goals

Platform thinking is a solution to improve the reuse of various types of assets for multiple products. This research focuses on technological knowledge as an asset to platform development, while also taking a step back to examine the reuse problem to which platform thinking offers a solution. Two goals have been formulated: (1) frame the problem of missed opportunities for technology reuse, and (2) propose and test methods, processes or tools used by large multi-technological companies to support repeated integration of their technologies in different products or processes. The reason why the focus is on large companies with multi-technological products is because they are assumed to possess the most urgent need for such support and also constitute a more difficult case to solve due to the high complexity, availability and distribution of their technological assets. Hence, the unintentional reinvention of previously developed knowledge and technologies is assumed to be more likely in those companies, even though the results may be generalizable and useful to many other types of companies as well.

1.3 Delimitations

The empirical data gathered through this research have been gathered from only one company, whereby the study is aimed at and delimited to technology reuse in companies resembling VAC—such as other suppliers developing and producing low-volume products for high-technology industries.

Our focus has been on activities and assets that exist *within* firms. Thus, the possibility of accessing technological knowledge through relations with other companies has neither been acknowledged nor discussed. Research on 'open innovation' and joint development of products and technologies in alliances or across the supply chain has, therefore, been deliberately excluded from the literature reviewed.

A common object of study for the research on the management of technology is patents. Although the patent system is partly designed for disseminating technological knowledge, it has not been studied during the course of this research. Arguably, the usefulness of patents for sharing knowledge is limited by their formal style of writing.

However, patents play an important role for both monitoring the development of new technologies in other firms and for protecting technologies developed in-house, and may have implications for this research that might have been overlooked.

1.4 Thesis Structure

The subsequent chapters of the thesis are outlined as follows:

Chapter 2 is an introduction to literature relevant to the study of this topic. It has been collected over the course of the project and has continuously contributed new ideas and perspectives.

Chapter 3 presents the strategy and methodology used for conducting this research, as well as important considerations for evaluating the quality of the academic results.

Chapter 4 collects the results from the appended papers and summarizes them in order to provide a coherent body of findings to discuss in subsequent chapters.

Chapter 5 is where my results are discussed in relation to the research questions and the criteria for research quality from Chapter 3.

Chapter 6 presents a conclusion of the findings and summarizes the contributions of this thesis.

Chapter 7 elaborates on some interesting aspects for advancing this research topic and continuing to support the research goals outlined.

2 FRAME OF REFERENCE

2.1 Technology Development and Integration

Working fast and effectively when developing new technologies has become an important competitive advantage (Katz and Allen, 1984; Wheelwright and Clark, 1992). However, the development of new technology is often mismanaged and efforts often fail to produce their intended effects (Eldred and McGrath, 1997a; Cooper, 2006). A common reason is that technology development is performed using the same set of processes and methods as were used for product development, which leads to poor innovation, less robust solutions, and potentially missed deadlines and cost targets (Schulz et al. 2000). Instead, less formal processes and organizational designs are needed for the development of technology, during which the pressure for productivity and control is reduced to make room for innovation (Katz and Allen, 1984).

'Research and Development' (R&D) is commonly used as a collective term to describe the organization and processes that generate new knowledge and products within companies. Several different terms are used in the literature to differentiate the early stages of R&D, i.e. the phases of 'research', including, but not limited to, 'basic research', 'applied research', 'fuzzy front end', 'technology development', 'advanced engineering' and 'pre-development'. The common theme is that all these terms, although they cover different ranges of the research phase, refer to activities that occur prior to the phases of 'development' or 'product development'. In this thesis, the term 'technology development' is used broadly to cover all of the above terminology, except for those types of basic research that are exploratory to the extent underlying intentions exclude the application and commercialization of the results. Iansiti (1998 p.12) neatly summarizes the traditional model of an R&D process:

> "Research projects, aimed at the creation of technological possibilities, are optimized for the investigation of rapidly changing knowledge domains. Once enough is learned about these knowledge domains, research defines the technological possibilities available, which are transferred to the development organization. Development activities are optimized to execute complex tasks. These involve adapting the (now stable) set of technological possibilities to the complex requirements of the application context."

Technology development and product development are often managed separately in order to equip them with suitable methods and process models (Schulz et al., 2000). Clausing (1994) identifies three primary reasons for having a separate technology development process: (1) allowing time for creativity, (2) setting up a creative environment, and (3) steering development toward flexible technologies that may be used in multiple products. Whereas some literature presents the alignment of technology development and product development as a temporal division of the same process (Eldred and McGrath, 1997b; Cooper, 2006), albeit with some overlap, Clausing and his colleagues (Schulz et al., 2000) prefer to model them as two parallel streams, from which product development is collecting, or "fishing out", appropriate technologies from the technology stream (Figure 1).

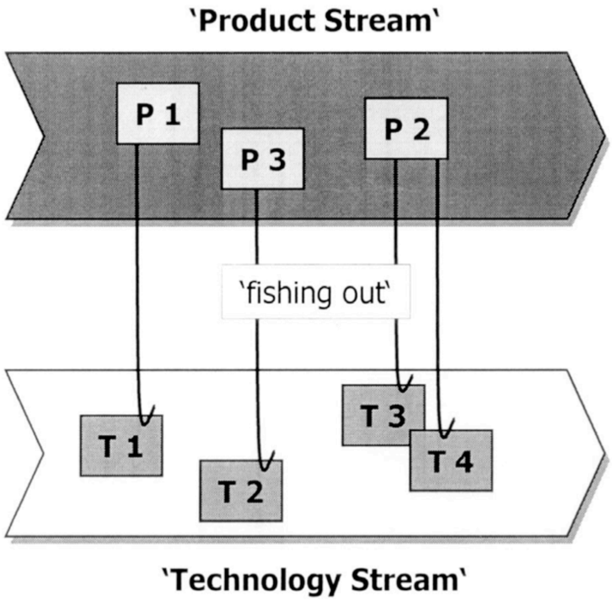

Figure 1. Product development and technology development as separate 'streams' (Schulz et al., 2000).

Based on his review of the literature, Nieto (2004) concludes that a technological innovation process, which corresponds to the technology development process, is primarily characterized by being continuous, path dependent, irreversible and affected by uncertainty. Further, Nieto (2004) argues that uncertainty is the most important characteristic and distinguishes between three different types:

(1) Technical uncertainty – whether a technical solution will work as intended.
(2) Uncertainty about future use – for what applications a specific technology will be suitable.
(3) Uncertainty about future evolution – how the usefulness and characteristics of a technology will evolve during its development.

Process models have been designed specifically for dealing with uncertainties in technology development. Cooper (2006) has proposed a model adapted from his original 'Stage-Gate' model, which was created for product development, to fit the unpredictable nature of technology development (Figure 2). The traditional Stage-Gate model assumes that there is a target market, defined customers and a clear view of potential future product features, and requires detailed analyses to pass a project on to the next stage. A technology development Stage-Gate, on the other hand, uses qualitative assessment about the potential value of the concepts to support decisions on whether further experimentation and testing is worthwhile (Cooper, 2006). In a case study with six hardware companies, Högman (2011) found that all of them used gate-based processes for early development that were designed to allow greater flexibility and adaptation than the traditional Stage-Gate model. Whereas the case companies reported effects of improved logic, structure and transparency of development, Högman (2011) also found evidence from cases reported in the literature where the Stage-Gate approach had infused excessive bureaucracy and inflexibility on the development of technologies.

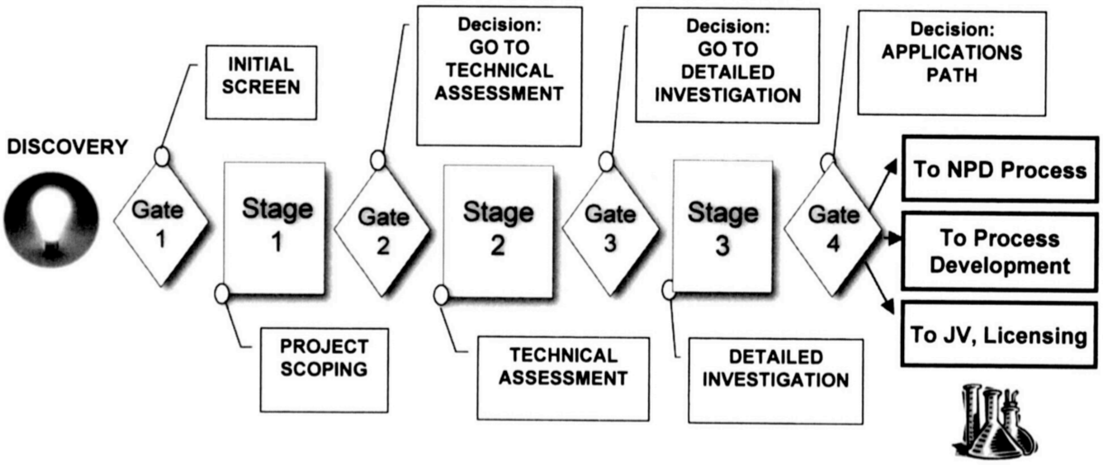

Figure 2. The technology development Stage-Gate model by Cooper (2006).

Other authors have also proposed adaptions to the Stage-Gate model for technology development. Whereas Cooper's (2006) adapted model still has a defined set of stages and gates, the model by Eldred and McGrath (1997b) allows for a flexible number of stages to fit the needs of a particular technology. Detailed planning is then performed for only the subsequent stage to define what deliverables are expected at the next gate. By deciding on a minimum quality level of these deliverables, a company can also avoid the common mistake of having wishful thinking allow a project to continue despite having missed its targets, instead creating an environment of "fast failures" to quickly free up resources for the benefit of other promising technologies (Ajamian and Koen, 2002). There is always the risk of rejecting ideas that might have turned into successful products given more time and resources for development. Reinertsen (1999) argues that the optimal strategy for accepting and rejecting ideas during a technology screening depends on three measures: the cost of screening an idea, the time it takes to screen this idea, and the effectiveness of the screening, i.e. the rate of correctness in valuing ideas for their commercial potential. For example, if good ideas are in abundance, the consequence of mistakenly rejecting one is low since another good idea is likely to get funded instead. Also, if time-to-market is considered important, adding another screening phase that delays the process by a couple of weeks may be more harmful than allowing some inferior ideas go through an additional stage of development before being rejected.

The transfer of technology between technology development and product development projects is complicated for various reasons, and the effort required is often underestimated (Eldred and McGrath, 1997a). Rather than a simple handover of documents and prototypes, a continuous process of transferring knowledge is generally needed to ensure a successful transfer, as is mutual adoption of the technology and application environment between the transferring parties (Eldred and McGrath, 1997a; Leonard-Barton, 1988). Eldred and McGrath (1997a) discuss three important dimensions of the transfer activity; program synchronization, technology equalization and technology transfer management. Program synchronization refers to the temporal alignment of the development processes, during which an optimal transfer would imply that a technology is ready for transfer at the same time as the product concept is about to be decided. Technology equalization is the process by which issues related to the enabling of a technology for its intended application are addressed, e.g. by preparing and developing the interfaces to other technologies and systems. Since technologies can seldom be tested in a fully representative environment in advance, such enabling can be highly problematic (Leonard-Barton, 1988). Also, product developers often perceive the results transferred as being insufficiently prepared for implementation (Eldred and McGrath, 1997a; Nobelius, 2004). Finally, technology transfer management deals with the operational details of defining roles, conducting technology assessments and making plans for managing the transfer.

By measuring the maturity of a technology, the remaining risks and costs of further development can be estimated to facilitate the decision of when the technology may be ready to be transferred to product development (Nolte, 2008). The most widely adopted metric for assessing technology maturity is Technology Readiness Levels (TRLs), which were originally developed by NASA (Mankins, 1995). The scale has nine levels (1-9), where the highest levels indicate the existence of a complete prototype that has been verified in environments that closely resemble its intended application. On the other end of the scale, technologies with the lowest TRLs are still undergoing stages of basic research, whereas the middle levels often correspond to proof-of-concepts in lab environments. A full overview of the scale is presented in Figure 3.

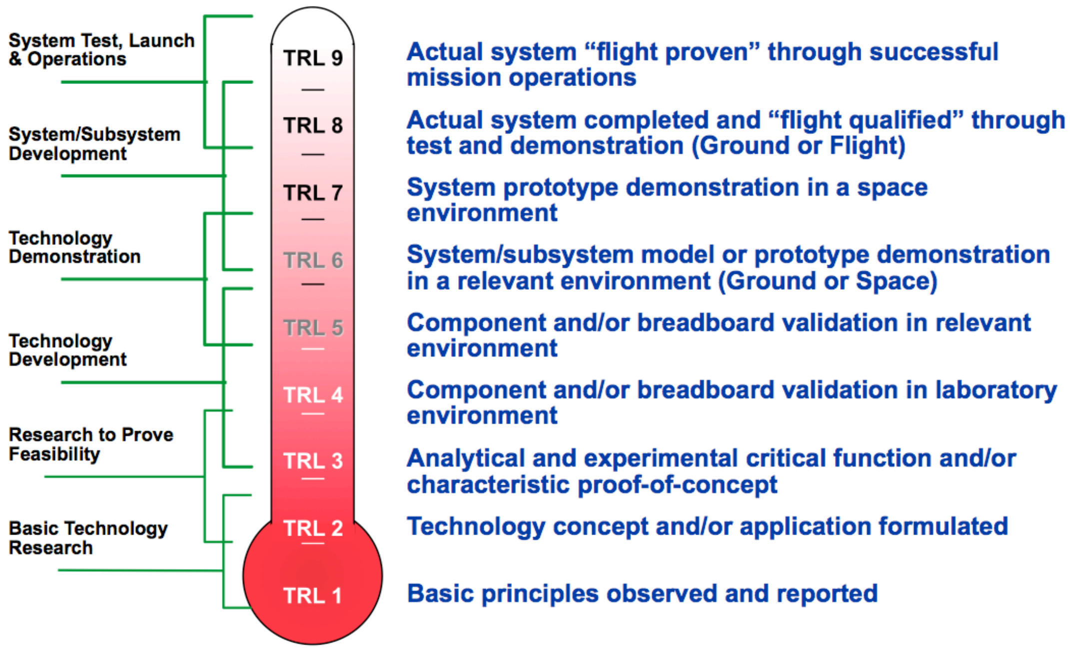

Figure 3. Technology Readiness Levels (TRLs) (Mankins, 2002).

Extensions to the TRL scale have been proposed by various researchers to account for other factors that are important when assessing the readiness of a technology. Sauser et al. (2008) address the uncertainties derived from interrelatedness between technologies and propose a separate readiness metric called Integration Readiness Level (IRL), intended to be used for the interfaces between related technologies. Together with their TRLs, these IRLs add up to a System Readiness Level (SRL). Other metrics focus on e.g. the difficulty of advancing through the TRL scale (Mankins, 2009), while yet others exclude the TRL scale and focus on assessing risks along different dimensions to provide a holistic picture of readiness (Clausing and Holmes, 2010).

2.2 Technology Planning

To conquer the general tendency to prioritize short-term projects, many companies warrant a dedicated budget for exploration and technology development to balance a project portfolio (Cooper, 2006). Based on that premise, the challenge is to allocate those resources most effectively among the ideas and options available. Given the uncertainties of predicting the outcomes of technology development, such strategic investment decisions face two trade-offs (Wernerfelt and Karnani, 1987). The first trade-off concerns the timing to invest in new technologies, thus deciding whether to take a leading role in their development or waiting for others to conduct additional testing first. The other trade-off is between investing in either focused or flexible technology options, whereby a focused option may lead to greater success at the cost of higher risks. Wernerfelt and Karnani (1987) argue, in a general case, that strong competition favors early investments, and since large companies can afford to wait and then use their resource advantage to catch up with "first-movers", small companies need to make more focused investments than do large companies. Decisions under uncertainty are also discussed by Levinthal and March (1993) who focus on how to optimize 'knowledge inventories', defined as collections of information and experience on "products, technologies, markets, and social and political contexts" (p.103). The challenges inherent in optimizing such inventories, they argue, concern the uncertainties of what may be needed in the future; in advance you cannot know precisely what you will need and when you know what you need, it is often too late to acquire that knowledge.

In a framework for technology portfolio selection, Schulz et al. (2000) analyze technologies through the lens of their intended products and markets. They assess technology performance along four dimensions: (1) contribution to customer satisfaction, (2) technological strength, (3) technological maturity and (4) superiority, i.e. the competitive advantage offered. The technology portfolio can then be mapped in a "Bubble Diagram" (Figure 4) that measures those four dimensions, together with a fifth dimension outlining the trend for its contribution to customer satisfaction and strength. The map provides a visual representation of the portfolio that can be useful for deciding on future investments.

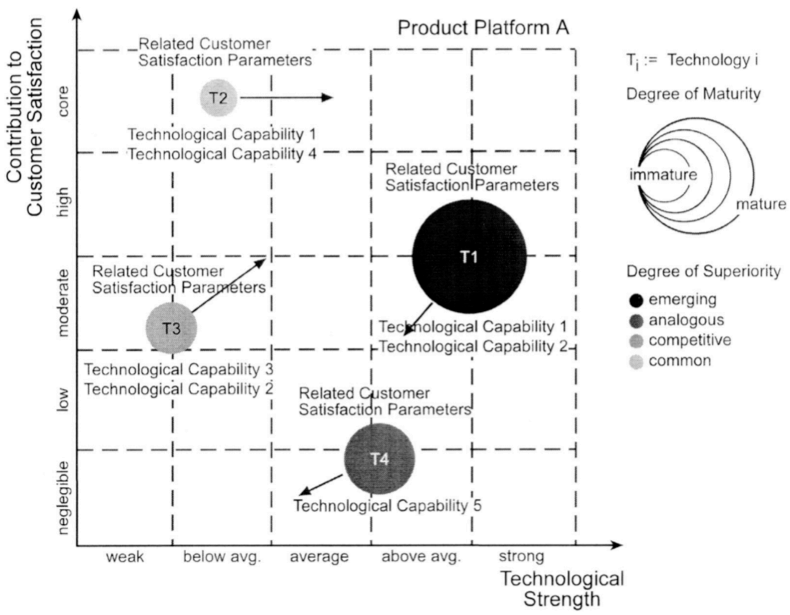

Figure 4. Bubble diagram for mapping a technology portfolio (Schulz et al., 2000).

To decide where to invest resources, a portfolio of technologies can also be mapped with technology attractiveness along one axis and the company's relative strength in that technology along the other (Figure 5) (Jolly, 2003). Jolly (2003) provides an extensive list of criteria that can be used for assessing technologies on those two dimensions and provides suggested weighting derived from a panel of top-managers. He concludes that employing all those criteria for each technology may be too costly, and recommends focusing on, e.g., impact on competitive issues, span of possible applications, barriers to imitation and how closely related a particular technology is to the core business of the company.

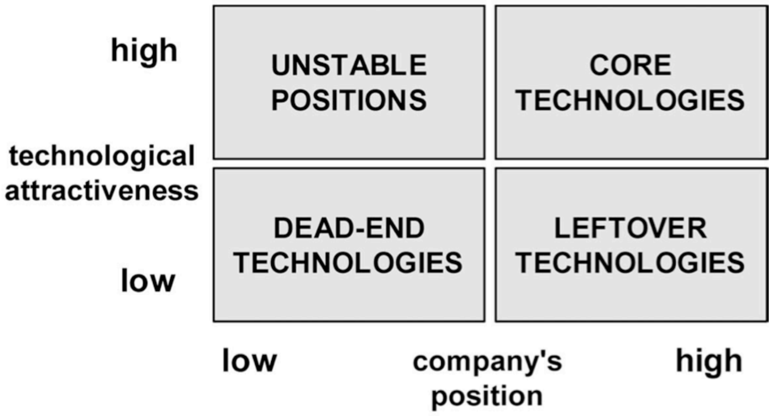

Figure 5. Alternative tool for mapping a technology portfolio (Jolly, 2003).

Though the uncertainties of technological evolution are inevitable, there are techniques for forecasting what might happen and which technologies may be used in future products in order to support decision-making. Drejer and Riis (1999) argue that few companies use these techniques systematically, possibly because of their static nature and technical focus. They propose adding a market development forecast to also consider the functionality that may attract future customers. Further, they emphasize the importance of integrating the technological forecast into the functional forecast. Since expertise in technology and market drivers are seldom possessed by the same people or even within the same departments, the forecasting is dependent on an extensive cross-functional dialogue within companies (Drejer and Riis, 1999).

Technology roadmapping is a popular example of forecasting techniques that integrate the planning of technologies and products. It is created by identifying products likely to suit a future market, then deriving their functionality and technologies needed to fulfill this market. The technologies and products are plotted on a timeline to provide an overview of planned development projects (Figure 6). Such a timeline can support both strategic management and detailed planning by including a planning phase for the following two to three years and a vision phase covering additional years into the future (Groenveld, 1997). The creation of system-level technology roadmaps needs to take place on a high level in the organization to align the views of different functional areas, in addition to aligning long-term and short-term planning (Petrick and Provance, 2005).

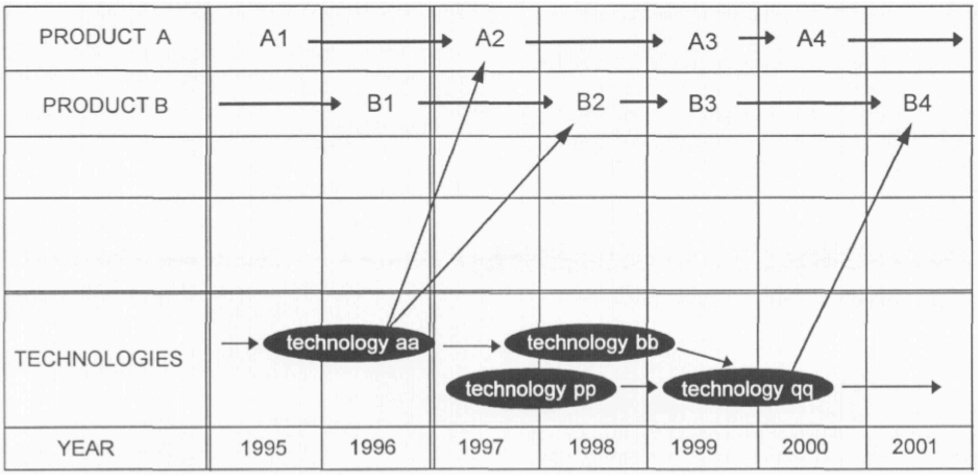

Figure 6. Technology roadmap as a planning tool (Groenveld, 1997).

2.3 Engineering Reuse

Engineers intuitively reuse previous designs and knowledge when performing new design tasks, either by complete carry-over of parts or through reuse on an abstract level, such as concepts or knowledge (Schulz et al., 2000; Smith and Duffy, 2001). Inspired by reuse methodologies from software development, Duffy et al. (1995) have developed a model for improving the effectiveness of reuse in the context of engineering design. With a formal—instead of ad hoc—approach, they argue that the understanding of the reuse process would be improved, allowing engineers and companies to increasingly leverage their knowledge. The model divides reuse into three processes: 'design by reuse', 'domain exploration' and 'design for reuse' (Figure 7).

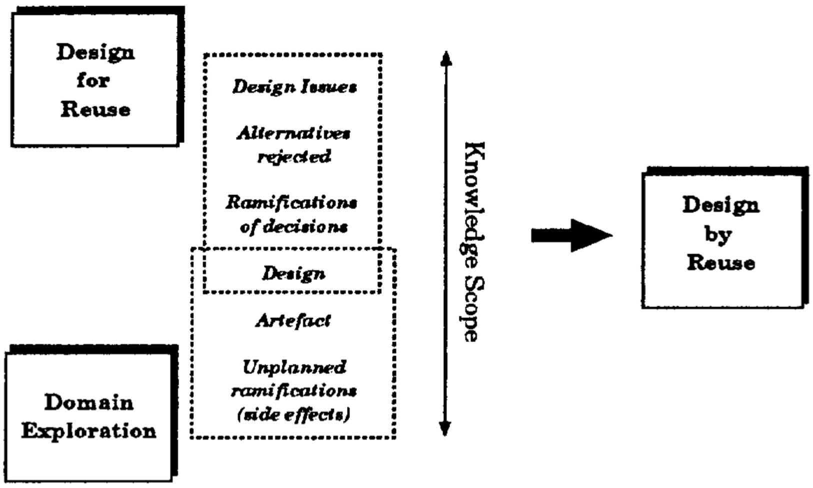

Figure 7. Categorization of reuse processes (Duffy et al., 1995).

'Design by reuse' is the process of designing something by applying previous knowledge, found either in the minds of experts or stored in documents. There are different levels of abstraction for such knowledge, ranging from physical artifacts to abstract concepts. The reuse of abstract level knowledge, as opposed to details of a design, requires additional knowledge relating to its history and rationale in order to revisit prior design decisions and support reapplication in a new context. The two remaining processes support the creation of reusable knowledge. 'Domain exploration' is the process of generating an understanding of the field of design where relevant knowledge can be found for handling design problems. 'Design for reuse' treats the capture of reusable knowledge during a design process. The purpose is to identify the knowledge that is suitable for reuse and then record it in a way that can be effectively revisited and reused. Consequently, documents containing such knowledge should be stored in an organized library to make them easy to find.

A comprehensive description of a process for the reuse of technologies, systems and software can be found in Davis (1994) who focuses on how to transform a business "from one-of-a-kind system developments to a reuse-driven approach". It starts with an assessment of a company's potential for adapting a reuse strategy, including assessment of market and product characteristics, as well as their capabilities in terms of e.g. the availability of reusable assets and organizational commitment to the reuse strategy. In addition to libraries of reusable assets, Davis (1994) lists five components of a reuse strategy:

- Deciding which products to develop with reuse and which to develop for reuse.
- How the business model should be adapted and how to finance the creation of reusable assets.
- What processes, methods and tools that are needed to manage reusable assets.
- How organizational structure, roles and responsibilities are affected.
- How to plan for the transition into reuse-based development.

A couple of key issues for successfully implementing a reuse strategy are highlighted, including the resistance from individuals whose work practices are affected by the change and the risk of investing in reusable assets that are not available when needed (Davis, 1994).

From the engineering reuse literature, there are also examples where the reuse of technological assets is in focus. Antelme et al. (2000) present a framework for engineering reuse in which reusable assets are listed as physical artifacts, processes, core competences and capabilities. They argue that all of these reusable assets are included in broad definitions of "technology", and continue to define engineering reuse as technology reuse. The authors divide technologies into either capabilities or products, with the latter defined as assets that can be offered to customers. This definition differs from the definition used in this thesis that treats embodied technological knowledge, corresponding to the "product" dimension in Antelme et al. (2000), as a separate type of reusable asset. The framework by Antelme et al. (2000) includes a scheme for categorizing technologies along five dimensions to support the identification of assets that may be reused. It also includes a diagram of the data flow between three processes of engineering reuse: Technology Creation, Technology Specification Management and Technology Utilization (Figure 8). The processes for technology creation and utilization roughly correspond to 'design for reuse' and 'design with reuse', respectively, in Duffy et al. (1995). Technology Specification Management is concerned with the storage of information and classification of technologies, as well as the decisions to implement and develop certain technological assets.

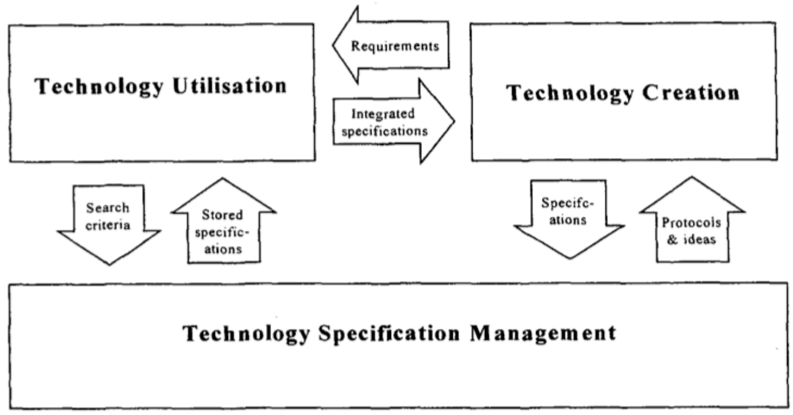

Figure 8. Data flow between engineering reuse processes (Antelme et al., 2000)

With the intention of making the concept of engineering reuse more practically applicable, Hunt et al. (2001) build upon the framework developed by Antelme et al. (2000) by suggesting a process that firms can follow for creating a strategy for reuse and a plan for its implementation (Figure 9). This process starts with the identification of a business need for reuse, which is important for backing decisions about resource allocation to reusability efforts. Next, the process prescribes an identification of available assets and analysis of options for reusing them, followed by a phase during which detailed plans are made for implementing the most viable options. Although the process gives an impression of being unidirectional, continuous and focused on planning for the utilization of existing assets, it implies the existence of other processes for further developing the assets that are identified as being promising candidates for reuse. Using a couple of hypothetical cases, Hunt et al. (2001) present examples of possible results from employing this process, including decisions to set up a knowledge library and design products based on reusable modules.

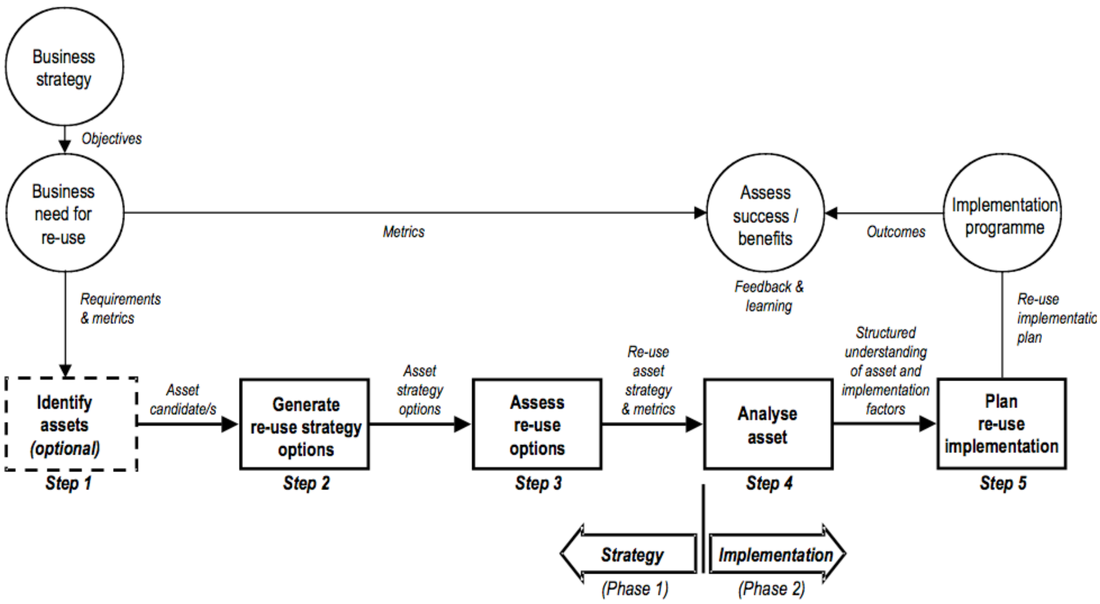

Figure 9. Process for creating and implementing a reuse strategy (Hunt et al., 2001).

2.4 Platform Development

One of the most prominent approaches to enable both ‘development for reuse’ and ‘development with reuse’ is platform development. The latter term refers to a strategy of defining the common characteristics of a family of products and, thereafter, making efforts to reduce their technical variation while maintaining, or increasing, their functional diversity in order to create a broad offering to the marketplace (Jiao et al., 2007).

There are two different views of platforms in the literature: one focuses on sharing physical elements among a set of products, while the other defines a platform more broadly to also include the logic, knowledge and people surrounding the products (Jiao et al., 2007). An example of the latter is the three-level framework for ‘platform thinking’ (Figure 10) provided by Meyer and Lehnerd (1997). The top level is made up of the actual product families offered to the market that come in a variety of configurations to meet a range of customer preferences. These products are built upon a shared set of features and components constituting one or more ‘product platforms’. There is often commonality also on a high abstraction level between different platforms that can be managed systematically. Meyer and Lehnerd (1997) refer to these common assets as ‘building blocks’, which make up the generic capabilities and knowledge concerning the market, technologies, customers and manufacturing processes that a company uses to develop its product platforms.

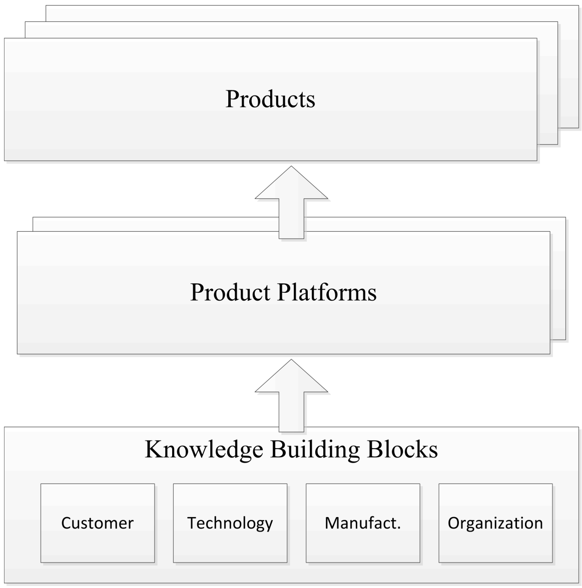

Figure 10. Technologies are leveraged in platforms, which are then further leveraged in products. Adapted and redrawn from Meyer and Lehnerd (1997).

The technology building block corresponds to the type of asset and reuse practice covered in this thesis, and there are other researchers who also devote their attention to those aspects of platform thinking, which can be referred to as ‘technology platforms’ or ‘technological platforms’. Jolly and Nasiriyar (2007) review the literature on technology platforms and conclude that there is an overlap between the concepts of technology platforms, core competencies (e.g. Prahalad and Hamel, 1990), and dynamic or combinative capabilities (Kogut and Zander, 1992; Marsh and Stock, 2006), which are presented further in Chapter 2.5.

Kim and Kogut (1996) use the term 'platform technology' and 'technological platform' to indicate a technology that has a wide range of potential applications, and which offers continued returns to the company when it is explored further and applied to new products. They studied start-up firms in the semiconductor industry and argued that in hypercompetitive markets, technological platforms offer an important advantage in terms of providing options for the diversification into new markets. The link between diversification and the possession of technological know-how, or platforms, is further explored by Nasiriyar and her colleagues (Jolly and Nasiriyar, 2007; Nasiriyar, 2009; Nasiriyar et al., 2010) who use patent data to show that companies are more likely to diversify into markets that share the same technological base, and that a broad technology portfolio increases the likelihood of entering new markets, arguably because of synergies and complementarity among technologies (Nasiriyar et al., 2010).

Rather than using the concept of technological platforms as a lens for studying the diversification strategies of firms, this thesis views it as an operational strategy for technology development and management, analogous to the concept of product platforms. However, both views of the technology platform concept are rooted in the same principles; the resource-based view of the firm (Wernerfelt, 1984), path dependency of technological competences (Teece et al., 1997) and the need for managerial capabilities to coordinate and deploy technologies in new products (Kogut and Zander, 1992).

2.5 Core Capabilities

The late 1980's and early 1990's saw the growth of a new field of research studying core capabilities of firms, which are knowledge assets that can reside in physical assets, skills, managerial systems and values of a firm (Leonard-Barton, 1995). Leonard-Barton (1995) divides capabilities into three groups, depending on their role in contributing value to the firm:

(1) 'Core' capabilities are the most strategically important capabilities, which cannot be easily imitated by competitors and are at the heart of the business.
(2) 'Enabling' capabilities are necessary for entering a business, e.g. certain manufacturing capabilities, but do not differentiate a company from its competitors.
(3) 'Supplemental' capabilities are value-adding to a firm, although they are neither necessary nor unique and can be replicated by competitors.

Another useful categorization of competencies is provided by Drejer and Riis (1999), who distinguish between three different types of competencies based on their scope and level of embodiment in the processes and interactions among different resources:

(1) A single technology, which can be embodied in a limited number of employees and equipment and is easy to identify.
(2) A network of interwoven technologies that are not meaningful by themselves, and for which knowledge on the interactions between the technologies are important.
(3) A complex system involving many departments and organizational units, where an even larger share of the competence resides in the synchronization and synergies among activities and resources.

For technology-based companies, capabilities mainly grow from the development of products and processes. Actions of both managers and employees affect how this growth takes place, and they can nurture it by considering the potential for building knowledge during various types of decision-making (Leonard-Barton, 1995). According to Prahalad and Hamel (1990), developing core competencies is not solely about investing in research and development. It can also be fostered by regarding competencies as resources to be shared on a corporate rather than on a business unit level, establishing a corporate roadmap of the competencies and technologies to build on for the future, entering strategic alliances, and explicitly identifying competencies to inform and encourage the entire organization to support their development.

Companies that over time have developed certain capabilities that make them successful in an industry run the risk of becoming rigid with regard to their competence base. As a company matures, it typically aligns its processes and organization to become as efficient as possible in leveraging its core capabilities, which creates an organizational inertia (Tushman and Smith, 2002). When market conditions no longer favor them, other companies are likely to quickly adopt new capabilities and take market shares. In technology-intensive industries, these changes are typically driven by technological innovation. If an innovation should alter the basis of competition on a market to make previous capabilities more or less obsolete, it is referred to as a 'disruptive innovation', which happened multiple times in the disk drive industry during its first decades (Christensen, 1997). Christensen (1997) showed that possessing the right capabilities and resources to pursue a new technological path was not sufficient for companies to survive a technological transition. This organizational inertia to adapt to change has been attributed to various factors, such as being too focused on the current customer base (Christensen, 1997) or using incentive systems that discourage new initiatives (Kaplan and Henderson, 2005).

For sustained competitive advantage, a specific type of capability is needed that allows firms to renew themselves and their competencies in response to change. This type of capability has been termed 'dynamic capability' (Teece and Pisano, 1994), or 'strategic flexibility' (Sanchez, 1997). This capability has two elements, one related to the innate flexibility of the resources possessed by a company and the other related to the capability to be flexible in the deployment of such resources (Sanchez, 1997). One of the most widely recognized remedies of technological inertia and a source of strategic flexibility is to balance the exploration and exploitation of resources against one another, and to balance incremental and radical innovation projects (O'Reilly and Tushman, 2004). Exploration is the process by which companies seek new knowledge and invest in new capabilities, whereas exploitation is the efficiency-focused activities of leveraging existing capabilities and products. The two terms are different in their nature and need to be realized by means of different strategies, structures, processes and cultures (O'Reilly and Tushman, 2004). 'Continuous innovation' and 'ambidexterity' are terms describing the ability of being successful at both operational effectiveness (requiring exploitation) and strategic flexibility (requiring exploration) at once (Boer and Gertsen, 2003).

2.6 Knowledge Management

In large project-oriented organizations, it often happens that multiple groups work with similar products, concepts and technologies. The effective reuse of technologies requires sharing and managing the knowledge between them to improve learning and avoid redundancy.

There are two types of knowledge-related activities in product development: knowledge creation and knowledge application (Ćatić, 2011). While knowledge creation is the type of knowledge that has gained most attention historically, the effectiveness of reusing knowledge for solving recurring technical problems is highly relevant to organizational effectiveness (Markus, 2001). Since the main objective of technology development activities is to generate new knowledge, strategies for knowledge transfer and reuse are imperative for increasing the usefulness of the results.

Knowledge can be categorized as either tacit or explicit, depending on the extent to which it can be expressed, codified and stored (Nonaka, 1994). There is disagreement on the relative importance of these two types (Markus, 2001), and different strategies are needed to support their reuse (Yeung and Holden, 2000; Ćatić, 2011). Explicit knowledge transfer is primarily supported by a codification strategy, which is often operationalized by storing knowledge in digital repositories. Tacit knowledge transfer, on the other hand, is best supported by a personalization strategy, which can be realized by solutions such as Yellow Pages information, face-to-face interaction and mentorship programs (Yeung and Holden, 2000; Ćatić, 2011).

Technologies have specific properties that differentiate them from other types of knowledge—stronger links to artifacts, better possibilities to codify their knowledge, and a clear practical purpose—which makes such knowledge easier to record and organize into a system (Granstrand, 1998). There are typically four different ways of documenting knowledge for future reuse; (1) unintentionally as a by-product of normal work, (2) as output of formal knowledge generation or knowledge transfer methods such as brainstorming, (3) through deliberate recording by means of structured formats such as test reports, and finally, (4) by spearheading initiatives to gather and index old records into reusable knowledge packets (Markus, 2001).

Much research has been conducted about how to capture explicit knowledge in digital repositories. There are two main concerns for making these repositories effective: the willingness of employees to contribute to them, and the rate at which users access and use them (Watson and Hewett, 2006). These concerns can be addressed by increasing the perceived value of the system to its users, which is mainly related to how updated and trustworthy the information is, and how easily one can find something useful (Watson and Hewett, 2006).

Markus (2001) provides additional important factors that affect incentives to use and contribute to knowledge repositories: whether the organization has a culture that promotes sharing, if contributions are rewarded and acknowledged, and the proximity between producers and users of knowledge. For the final factor, documentation for one's own future use offers the highest incentives, while the incentives to document for 'similar others' who may reciprocate the favor is lower, and to document for 'dissimilar others' provides the least incentives. Besides incentives, Markus (2001) highlights two other factors that affect the success of initiatives for knowledge reuse: the cost of creating repositories and the need for technical or human intermediaries to translate knowledge into formats that are useful to others. As discussed in Chapter 2.2, another problem is the uncertainty about what might be useful in the future (Levinthal and March, 1993). Depending on the variety and depth of its content, knowledge may be useful for different purposes. Broad or deep knowledge has more potential to be readapted to new contexts, whereas knowledge that is specialized can be quickly integrated into those products for which it was intended.

Knowledge repositories based on Web 2.0 solutions, such as blogs and Wikis, have been proposed as means of facilitating knowledge sharing, and some have even suggested such repositories can be used for transferring tacit knowledge (Standing and Kiniti, 2011). Yates et al. (2010, p.543) describe Wikis as "sets of dynamically created Web pages with content contributed directly by users in a Web browser". These repositories also require a culture of sharing and collaboration, as well as ease of use, in order to supply the intended effects. It has been reported that some individuals tend to voluntarily take on the role of "information shapers" who reorganize and edit content to improve readability and searchability for others (Yates et al., 2010). However, there is often a lack of policies on how to manage the content of corporate Wikis and who should be allowed to correct the information submitted by others (Standing and Kiniti, 2011).

2.7 Derived Research Questions

Previous research on why and how companies can benefit from the reuse of technologies has mostly focused on firm level issues, proposing generic management strategies for technology-intensive companies. Other fields of research provide insights into the challenges of applying reuse strategies on an operational level, but not explicitly for the purpose of, or with consideration to, the unique characteristics of technology development. The research questions (RQs) have been evolving over the course of this research project. Consequently, the current version is partially based on the results of the early studies conducted, which is why RQ2 and RQ3 assume that RQ1 will prove them relevant. However, the research questions have been fairly stable and since early versions, they have included such themes as learning, collecting information and managing technologies as resources.

RQ1: What are the barriers to efficient reuse of technologies within companies?

The first research question reflects an exploratory element of the research in which the problem of managing technology reuse is investigated more deeply. There are sound arguments in the literature for working strategically with portfolio techniques and platform development, but there is a need for additional insight into how these techniques are put into practice on an engineering level, and what may be the reasons why technology reuse is still perceived as a challenge in industry.

RQ2: How can a company expose its knowledge about technologies internally to increase its usefulness as an available resource?

Technologies primarily exist as knowledge in different forms. Reusing technologies is thus dependent on acquiring access to the information and knowledge about them, which may be difficult to locate and transfer. The limitations in access to technological knowledge were found to be a significant barrier to reuse during the quest for an answer to RQ1, and were, therefore, deemed relevant for further investigations.

RQ3: What are the opportunities for building support for technology reuse into product and technology development processes?

The second research question was focusing on how to support reuse from the perspective of the reuser, i.e. how to support development *with* reuse. Another way to support the reuse of a technology is to prepare for its reuse already before and during its development, i.e. development *for* reuse. The third research question addresses both of these aspects and focuses on how the arrangement and design of development activities may help developers and managers detect opportunities for preparing future reuse, as well as for reusing already existing knowledge.

3 RESEARCH APPROACH

3.1 Research Design

To explain the strategy behind the research, two methodological frameworks for research design are discussed. These frameworks have not been used proactively for guiding the research. However, they have been shaping the general practice of research within our department, which in turn has affected the applied research approach. Further, they have been supporting a retrospective analysis of the progress so far to indicate the need for future validation. The reason for including two different frameworks is that the research has been focusing both on a management level and on an engineering, or operative, level of analysis. These two frameworks are believed to supplement each other.

3.1.1 Design Research Methodology

Blessing and Chakrabarti (2009) propose a specific methodology for conducting research on topics related to 'design', i.e. conducting 'design research'. Here, design is broadly defined as the activities involved in product development, from a perceived need to a finished design. The authors argue that in order to contribute to both practical and academic communities, design research should strive to fulfill two purposes: to understand the object studied and to propose tools, methods, or guidelines useful to practitioners. Hence, there is greater focus than in many other research fields on the creative role of the researcher in designing new ways to deal with the issues studied. The Design Research Methodology (DRM) is a framework that includes four activities that are explained further below (Figure 11): (1) Research Clarification, (2) Descriptive Study I, (3) Prescriptive Study, and (4) Descriptive Study II.

The first activity of DRM is to clarify the ideas and assumptions that initiated the research project and formulate a goal for subsequent activities. The second activity is to find literature or empirical data to understand the object of study, which is often a problem recurrent in industry related to the design process. The third activity is to create tools, processes, methods or guidelines as proposed solutions to the problem studied. This third activity is a prescriptive phase involving a creative step that cannot be derived directly from empirical evidence. However, a systematic design process is proposed by the authors for guiding the development of such support. The fourth and final activity is to test the support in a real or representative environment and describe its effect in terms of actual and intended outcomes. Iterations among the steps are generally required since additional understanding provides feedback that may question earlier assumptions.

The ideas behind the research of this thesis came from a well understood empirical setting, i.e. the case company, with clear goals for the intended outcome. However, the understanding was largely based on the experience of researcher Ulf Högman who had been working at the company for many years. Hence, my first step was to identify and describe the situation through additional studies together with him and other colleagues, both for their academic relevance and for improving my own understanding. These studies used an inductive approach (Bryman and Bell, 2007) to generate theory on the topic based on the selected case and are reported on in Appended Papers A and C. After initial descriptive studies, a prescriptive phase followed during which a prototype IT tool was developed, which is also described in Paper C. A literature review was then performed to describe state-of-the-art research on engineering reuse and flexibility in order to clarify the holistic view of the topic (Paper B). Lastly, an overall process framework for platform-based development was created, which is presented in Paper D.

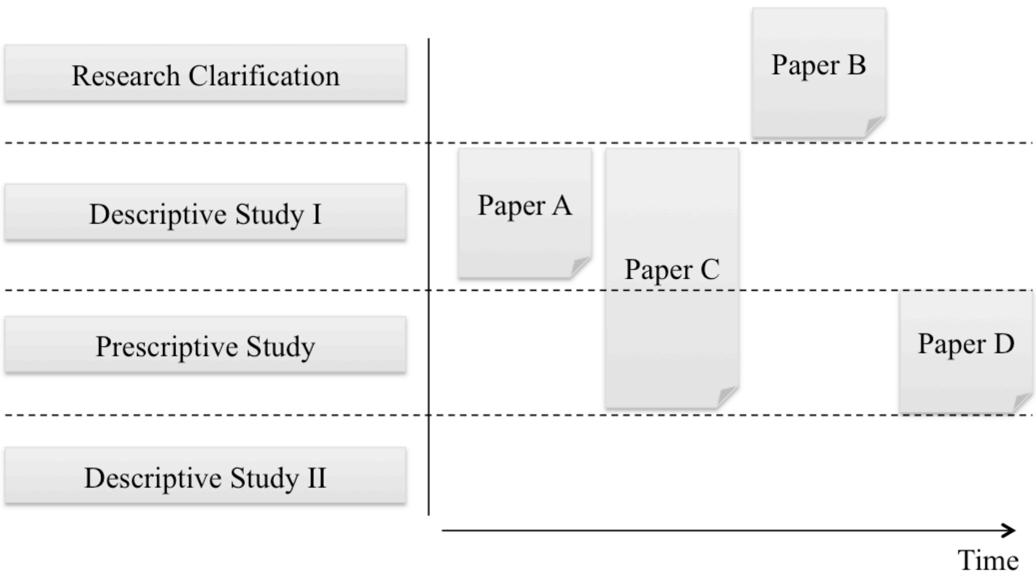

Figure 11. Appended papers mapped against the DRM framework by Blessing and Chakrabarti (2009).

3.1.2 Interactive Model of Research Design

The Interactive Model of Research Design by Maxwell (2005) includes five components to be addressed when designing qualitative research (Figure 12). When designing a qualitative study, rather than sequentially planning the components and their logic, an iterative process is needed in order to capture the integrative effects between them. Adjustments may also be needed as research is conducted to improve the fit between research strategy and the environment studied. The arrows between the components stress the importance of linking them to create a coherent whole. The elements forming the upper triangle establish the contribution sought by means of the project. This subgroup of components emphasizes that goals shall be relevant in relation to the existing theory, or 'conceptual framework', and that research questions shall point to areas that are interesting for extending current knowledge given these goals. When addressing the bottom triangle of the model, one should choose methods capable of answering the research questions and validating these answers for correctness.

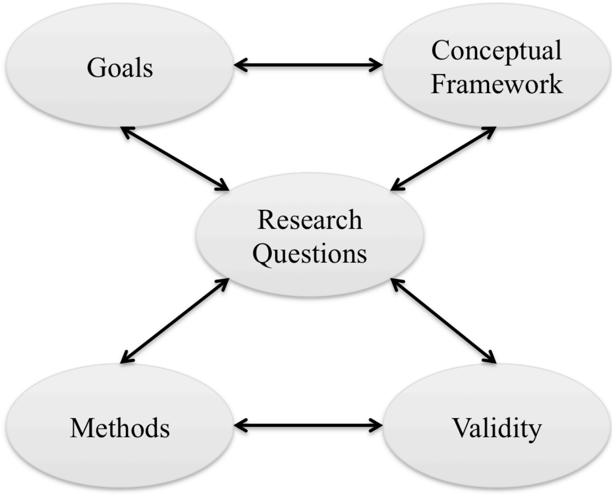

Figure 12. Interactive Model of Research Design (Maxwell, 2005).

This research has been reiterating the components of the upper triangle multiple times to find a common ground for the industrial need—or goal—behind the research proposal and existing literature about technology reuse. The case studies have served as a method for starting to answer the initial research questions and for guiding the research design. Earlier versions of the research questions targeted topics that were both too detailed and too generic, whereas the current version takes an holistic perspective and includes both exploration (RQ1) and prescription (RQ2 and RQ3). All three RQs are generic in the sense that they do not ask specifics about a case. According to Maxwell (2005), such questions typically require methods that elicit representative data, usually by means of quantitative methods or sampling techniques for case selection. The methods employed in this research are neither quantitative nor based on statistical sampling, raising the question of the representativeness of the data and the conclusions derived therefrom. The methods used were case studies at the company from which the goals of the research originated, as well as 'thought experiments' using both results from the case studies and from previous research found in the literature. These methods led to proposed answers to the research questions, which in turn lent themselves to future research employing methods better suited to test statistical conclusion validity (Cook and Campbell, 1979 cited in (Maxwell, 2005)). Hence, this thesis is a step along the way towards answering the generic research questions, reflecting the fact that this research will continue using the same or a similar goal. The validity aspect of this research will be further elaborated on in Chapter 3.3.

3.2 Applied Research Methodology

Appended Papers A and C are based on two interview studies at the case company, including informal meetings and discussions both before and after the interviews to gather contextual information. Paper B is a review of the literature, while Paper D is a compilation of results from previous studies by the research group and proposes and tests a methodology for platform development.

3.2.1 Interview study for Paper A

The first interview study examined technology transfer at the case company in order to improve the understanding of current practices and make way for improvements of processes. Data were collected from 22 semi-structured interviews, document analyses, and recurring informal discussions with employees from the Technology and Product Development Departments. This enabled an examination of the highly contingent context in which technology development is performed, leading to difficulties identified by those working on the processes. A majority of the interview material was reused from a previous study on technology transfer at the case company that had been performed by Bengtsson and Stetz (2009), covering all types of technologies. Five additional interviews were performed in 2010; since manufacturing methods were regarded as the most difficult technologies to transfer and were common among the technology development projects, these interviews primarily focused on manufacturing technologies. While many of the findings were valid for all types of technologies, this focus on manufacturing technologies may have affected which issues that were regarded by the interviewees as most important and what types of documents that were delivered from the technology development projects. The recordings of all interviews were transcribed and relevant statements extracted and categorized. Technical documents and process descriptions of technology development were also studied in order to supplement interview data and gain deeper insight into development activities.

3.2.2 Literature study for Paper B

The study reviewed the literature about reusability and flexibility of assets from such research fields as Systems Engineering, Technology Management, Knowledge Management and Strategic Management. The literature was found by first searching the ISI Web of Knowledge for the keywords “flexibility”, “reuse”, or “platform” in combination with such keywords as “technology” or “design”. The articles deemed relevant among the initial results of this search were all categorized into “Business Economics” by the search engine, which was added as a filter to focus subsequent searches.

The articles found during the first round were screened for relevant references, and additional literature references for the concepts and methods mentioned were sought through Google Scholar (http://scholar.google.com) in order to obtain a comprehensive response to these narrow searches. Some articles focused exclusively on the reuse of software code and were omitted from subsequent searches as they were perceived to treat characteristics too software-specific for the scope of the paper, and because our previous knowledge was too limited to perform a correct analysis of such data. The literature on technology development and platforms was primarily based on previous studies of the topic performed by the research group.

The literature study on the topics addressed was not comprehensive. Instead, it showed the diversity of topics that lent themselves to be found when searching for ways to support reuse and flexibility. Even late iterations of the literature search provided new relevant materials. However, at a certain point, it was decided that the results were extensive enough to satisfy the purpose of providing an overview of relevant literature.

The articles were categorized according to the types of solutions addressed for improving flexibility and reuse. This categorization scheme is one of the main results of the review and forms the structure for the discussion.

3.2.3 Interview study for Paper C

The purpose of the second interview study was to learn how information about technologies is stored and retrieved at the case company. Data from previous observations of meetings, workshops and presentations attended, as well as from twelve new semi-structured interviews were collected. The interviews lasted for about 90 minutes and focused on technology information, platforms and IT support. The interviewees were chosen from the development organization and occupied such roles as technology developers, manufacturing method "owners" or managers from either the project or line organization. All interviews were recorded and transcribed and transcriptions were sent to the interviewees for correction.

Further, a prototype, or "demonstrator", of an IT tool for sharing technology information was developed before the interviews and presented to the interviewees for their comment and feedback. The demonstrator was shown at the end of the interviews to avoid biasing answers to the other questions.

3.2.4 Theoretical work for Paper D

The last of the appended papers proposed an holistic approach to platform development based on the ideas collected and tools developed within our Systems Engineering and PLM Research Group. The contribution was the integration of the various components, developed through joint discussions and writing sessions among the authors. The case of configuring an existing product concept at the case company was used to exemplify the approach.

3.3 Quality Criteria

Qualitative research in general and case studies in particular should be analyzed from a couple of different perspectives for validity and reliability to address their scientific contribution. This section presents the theory on how to address validity, whereas the discussion of the validity of this research is presented in Chapter 5.

Reliability as a concept for the verification of research deals with the reproducibility of a result or measurement (Blessing and Chakrabarti, 2009). Bryman and Bell (2007) distinguish between three forms of reliability: stability, internal reliability and inter-observer reliability. With stability, measures or tests can be repeated with the same results under equal conditions, provided that the first test does not influence the results of subsequent tests. Internal reliability means that multiple measures used for the same construct actually measure it. Otherwise, the measures will not correlate and cannot be used to attribute a single score to the variable measured. The last form of reliability, inter-observer reliability, represents the consistency with which multiple observers perceive and categorize a subjective measure, e.g. when analyzing open-ended questions from an interview.

Validity can be interpreted as the quality of the relationship between reality and the descriptions, interpretations and conclusions generated from the research. Full validity is useful as a goal but cannot be achieved (Maxwell, 2005). It is useful to discriminate between internal validity, i.e. the fit between observations and the theory derived from them, and external validity, which is the ability to generalize findings to settings other than those provided by the data (Bryman and Bell, 2007). Due to small sample sizes, case studies are inherently weaker for attaining external validity than large-sample cross-case studies (Gerring, 2007). Hence, case studies are typically used for exploration and hypothesis generation rather than for hypothesis testing, something that makes them more sensitive to internal validity threats. Nonetheless, it is imperative that the implication of case studies be analyzed in relation to a larger population in order to integrate them into other studies in the field (Gerring, 2007). Consequently, when conducting an exploratory case study, consideration should be given to what the case represents, in addition to preferably testing the hypotheses generated by using subsequent cross-case studies (Gerring, 2007).

Two threats to research validity that are particularly important to address in qualitative research are researcher bias and reactivity (2005). The first threat, researcher bias, is a threat to the objectivity of the research and manifests itself through the selection of data by researchers that fit their preconceptions or that catch their attention based on previous knowledge. Although researchers always bring their perspective based on previous knowledge and beliefs, the threat to research validity can be limited by raising an awareness thereof and reflecting on what these preconditions might be and how they might affect the research (Maxwell, 2005). By being transparent on the way interviewees were selected, the number who were interviewed and the roles they occupied in the organization studied, the possibility of evaluating representativeness of the conclusions drawn would improve (Bryman and Bell, 2007). The second threat is reactivity, which concerns the effect that a researcher has on the individuals studied. It is especially relevant in interview studies where the interaction may influence the answers (Maxwell, 2005). Fortunately, there are a couple of ways to limit this influence, e.g. avoiding leading questions (Maxwell, 2005), and letting the interviewees comment on the transcriptions and conclusions (Bryman and Bell, 2007).

Maxwell (2005) recommends eight techniques that can be used for testing validity in qualitative research:

1. **Intensive, long-term involvement**, which provides more robust data and opportunities to test hypotheses.
2. **Rich data** through e.g. comprehensive transcripts of interviews that cover different aspects of a situation.
3. **Respondent validation**, i.e. letting subjects review the data and conclusions derived based on their responses.
4. **Intervention** into the research setting to examine effects of proposed solutions.
5. **Searching for disconfirming evidence** to avoid ignoring data that do not fit a theory.
6. **Triangulation** by which information is collected using a variety of methods and sources to mitigate the risks of bias.
7. **Quasi-statistics** whereby quantitative claims can be tested and data made more explicit.
8. **Comparisons**, e.g. using multiple case studies, which provide the opportunity to isolate variables in order to study causality.

4 RESULTS

The four appended papers cover different aspects of how to leverage the potential for internal technology reuse at a company. The same case company was studied from various perspectives, which helped finding coherence among the findings and proposed solutions.

Paper A explored the process of transferring technologies from technology development to product development, revealing barriers for both the transfer of technological knowledge and for integrating technologies into products. These processes are both highly relevant for the reuse of pre-existing technologies even when the processes of technology development and technology integration are more separated in time and space than in the case studied.

For a technology reuse strategy, such as the technology platform approach discussed in this thesis, the intention is to prepare for the reuse of previously developed technological assets in new products and processes. Hence, there is a need to store and transfer the knowledge in ways that make it accessible to future users, something that was considered in Paper B, which explored ways in which developers and managers access information about technologies. Further, Paper B tested a hypothetical solution for improving access by means of a Wiki-based technology catalogue.

Paper C explored different practices and methods for improving the reusability of assets in product development that are already available in the literature. The rationale behind this review was that techniques probably exist that address the reusability of assets other than technologies that these can serve as inspiration and complements to strategies for technology reuse. Some of the techniques found target the reuse of technological knowledge, directly or indirectly, whereas the majority focuses on products and product concepts.

Paper D presents a framework composed of methods for technology and product platform development proposed by our research group. The paper discusses how these components fit together, and theoretically applies the framework to the case company to show how they can be addressed using an integrated development approach. The technology platform is an integral part of the systematic reuse strategy that we have chosen to call a 'technology-based configurable platform approach'.

4.1 Paper A

Title: *Assessment of Readiness for Internal Technology Transfer*

The purpose of Paper A was to explore how technology development results are transferred to product development to gain an insight into the processes that are useful for securing successful technology transfers. The case company described in Chapter 1.1 develops and produces components and subsystems to the aerospace engine industry. In order to secure technology readiness before committing to integrating them in new products, the company had divided its development process into technology development and product development. The case provided a setting to study the challenges of deploying technologies and transferring knowledge between teams, which was assumed to be applicable to situations of redeployment of technologies as well. The data were collected through interviews, discussions and workshops with managers and developers, as well as by studying documentation of project objectives and development processes.

The company used a Stage-Gate process composed of six gates based on Technology Readiness Levels 1-6. The first stages were often passed already at the outset of their technology development projects, and the gate reviews typically started with TRL 3 or 4. The criteria for passing one of these gates were found in checklists based on an interpretation of the TRLs in Mankins (1995). In the documents studied, the fulfillment of these checklist criteria was one of the main goals when starting a new technology development project, something that was confirmed by the interviewees who perceived these checklists as a reference tool for deciding on deliverables from their projects. In addition, based on the arguments that risk reduction is crucial for success, while cost reduction often is the motive for development in the first place, interviewees believed that creating a robust and cost-efficient technology was the main objective of technology development.

When asked about the transfer process and the challenges inherent therein, the interviewees presented several factors that might pose a risk to successful transfers. These factors may be categorized into the following: (1) knowledge transfer, (2) implementation readiness and (3) unclear goals. Concerning knowledge transfer, they emphasized the importance of proving training for the recipients of new technologies in addition to handing them documentation and instructions. Without proper training, there was a considerate risk that they would not be able to apply the technologies as intended but were rather having to deal with future problems emanating from this lack of training. Neither would they be confident in the performance of these technologies, increasing the risk that these new technologies be substituted for more proven ones instead.

Regarding the second risk to successful transfers, the gate assessment checklists used at the company thoroughly tested the degree to which a technology was understood. However, the checklists were not equally precise in testing whether an organization was prepared to start using a certain technology. The interviews revealed that many problems related to long lead times in product development and production were attributable to insufficient preparations in such areas as the education of operators, the purchase of equipment or the planning of production cells. These preparatory steps were not stated as objectives for the technology development projects and could typically not be initiated until there was a commitment for introducing the new technology into a specific project. This led us to the third risk of how to decide on technology development goals. Some technology development projects were designed to deliver results on a specific product, which enabled the transfer to start early by involving the recipients in the project. However, other technologies had been developed toward an anticipated future general need, i.e. no clear target for the delivery of results had been adopted and it had become impractical to prepare the organization for their introduction.

The paper concluded that these problems may likely be supported by solutions from the literature and from extensions of current practices. One recommendation was to ensure that the transfer process starts well ahead of project completion and that some project members continue serving on the product development team. Another recommendation was to extend the assessment checklist to include more implementation-related criteria in order to ensure that technologies were ready to be introduced on time, as opposed to merely being understood well enough to trust their capability. Another factor affecting the assessment of how prepared an organization was in using a new technology was the difficulty of developing it beyond TRL 6, which is currently performed within the product development projects. A metric for addressing this difficulty of further development would provide a useful complement to TRLs when deciding on technology integration.

4.2 Paper B

Title: *Improving Flexibility and Reuse for Technology Development*

The purpose of Paper B was to find reuse strategies from a variety of research fields and relate them to the technology context. The term flexibility and its synonyms are often used to describe characteristics that make products and technologies more reusable, which is why these terms were also included in the search for relevant literature. The articles found cover reusability aspects from both a strategic and engineering perspective. The resulting framework was created to reflect the variety of opportunities available to companies wanting to increase their reuse of technologies developed. The framework categorized the literature into three types of activities for which technological reusability can be addressed: (1) development work, (2) technology selection and (3) organization of development.

There are a number of techniques for improving the reusability of products that may also be reinterpreted for the development of technologies. Platform development as presented in Chapter 2.4 is one of these techniques, whereby upfront planning for reconfiguration prepares a design for the exchange or scaling of components. Flexibility and robustness can also be designed into a product by e.g. modular design, overdesign and low functional coupling. To the extent that technologies are manifested in artifacts, these guiding principles can be considered when developing technologies for increasing their potential reusability.

When selecting which technologies to develop, there are a number of attributes to assess. In the opinion of Schulz et al. (2000), four attributes are needed to make a technology provide a competitive advantage; superiority, robustness, maturity and flexibility. Hence, by letting technology portfolio analyses also address the aspect of flexibility, e.g. with the ‘Bubble diagram’ (Figure 4) proposed by Schulz et al. (2000), there is a better chance that the value derived from reusability be appreciated and later leveraged. Technology roadmapping and forecasting are common techniques to help predict the technologies that will be predominant in the future by avoiding the development of short-lived technologies that will not be relevant for future reuse.

The localization of development teams and processes for sharing knowledge are two examples of how the organization of development affects the opportunities for reusing technologies. Within a functional organization, the experts within a certain field are located next to each other and keep up-to-date on the latest progress within their field. These experts have incentives for thinking strategically about the development of their assets and the risk of overlooking opportunities for reusing technologies is less likely than in a project organization where the same functions are carried out by many different project teams. The flow of knowledge is also important for making sure that the technologies available to the company are reviewed and applied effectively. With a combination of practices for documentation and personal interaction, both the awareness and access to technological knowledge would be increased, leading to opportunities to reapply them to new products.

The paper concludes that there is literature specifically targeting technology reuse; however, there is a larger group of literature concerned with similar topics in other fields of research. Although findings from this literature cannot perfectly fit technology management, there is the potential for reinterpreting them. The techniques for assessing the value of technology flexibility have not converged into a distinctive set of best practices. Future research can probably contribute to this field, facilitating the job of managers who make decisions on technology selection and development.

4.3 Paper C

Title: *Means for Internal Knowledge Reuse in Pre-Development – The Technology Platform Approach*

The management at the case company perceived a need to become better at reusing technological knowledge across different products. This paper presents the results of a study to provide deeper understanding of the causes of the perceived need and to test our idea about how information about technologies might be captured and shared within a company.

A 'demonstrator' was developed that used Wiki software to create a web-based catalogue of the technologies used within the company. The list of technologies was provided by the company, and a couple of sample pages were created to display the intent and type of content believed to be relevant based on previous experiences and discussions with the company (Figure 13). Ten interviews were conducted to explore the need for, sources of, and barriers to locating technology information during technology and product development. Towards the end of the interviews, the demonstrator was shown and explained in order to get feedback on the format and its potential, as well as its drawbacks.

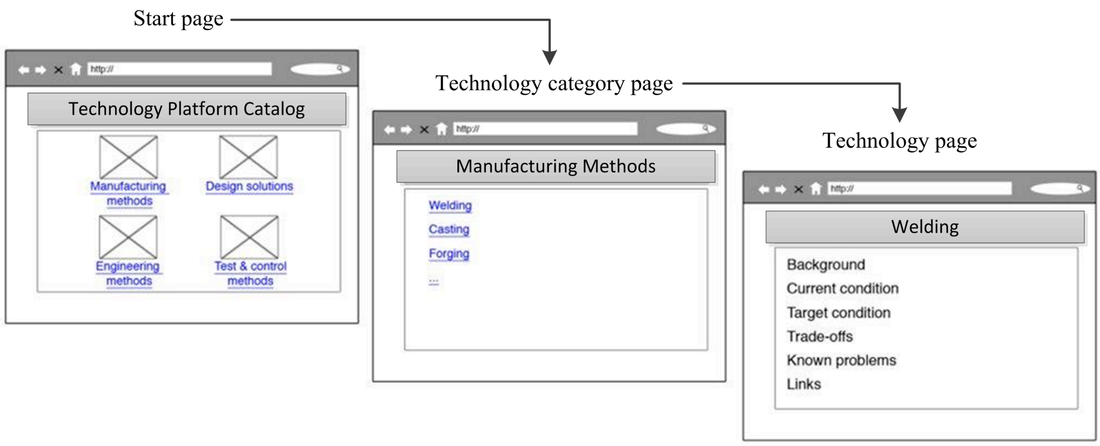

Figure 13. Overview of the Wiki catalogue demonstrator.

The type of technology information sought by interviewees depended on their role in the organization. The managers wanted to get an overview of the technology portfolio from different perspectives, to keep track of the progress on current development projects and learn when new technologies would be available for implementation. Developers, on the other hand, were interested in getting detailed information on design guidelines and cost estimates for applying technologies to products.

The study showed that personal contacts within the organization were the sources of information used the most. The process of looking for new information in databases and reports was restricted by the limitations of internal search engines and strict permission rights to access certain documents. To find information in reports, the interviewees needed to be aware of their existence in order to search for the official names of reports or authors. Asking colleagues or using one's own previous work to gain access to information and knowledge about technologies worked reasonably well, but interviewees also believed that they missed out on useful information and that searches were too time-consuming.

When the demonstrator was shown towards the end of the interviews, the comments confirmed our belief that there was a lack of centralized high-level information about technologies within the company. Although the validity of interviewee support was restrained by a small sample, such a catalogue was deemed useful for increasing awareness and understanding, as well as providing a starting point for finding detailed information. A couple of concerns were raised during the demonstrations: (1) how to assure that the information in the Wiki would be correct in a situation where multiple authors could contribute and there would be no review process before publication, (2) the fact that the core knowledge of the company would be collected in an open format might increase the risk that the information would be stolen or spread to competitors.

The conclusion of the study was that the opportunities for technology reuse could be improved by addressing and overcoming barriers to the use of codified knowledge. These barriers included: the searchability for reports and other documents, the level of technology awareness within the company, and the lack of a starting point for learning about technologies. The catalogue was perceived as useful to begin to overcome these barriers, and further research could serve to evaluate the benefits and limitations more closely to see what effects the catalogue might have on the design of development processes and the need for other types of documentation.

4.4 Paper D

Title: *An Integrated Approach to Technology Platform and Product Platform Development*

Paper D presented the technology Wiki from Paper C as part of an integrated framework for effective reuse of R&D assets. This approach provided an extension of the concept of product platforms—which has mainly been focusing on the reuse of physical components in product family development—by also integrating the reuse of product concepts and technologies. These latter assets are also reusable but differ from reusable components in that they are more difficult to model and need to be adapted before implementation, thereby adding new requirements to development processes and information management practices.

The prescribed approach constitutes a compilation of results from previous studies by the authors and was presented both as a generic methodology and as a case applicable to an industrial company. The case was constructed from interviews and workshops conducted at the case company with the results partially validated through discussions with company management.

The approach involving a 'technology-based configurable platform' consists of two parts; a technology platform and a configurable product platform. As presented in Paper C, the technology platform can be viewed as a collection of knowledge about technologies within the company. This knowledge is organized in a systematic way and is continuously updated based on both new technology development projects and previous applications of the technologies in products and manufacturing. The platform uses a Wiki that supports the development of new product platforms and their derivative products. In the configurable product platform, technologies have been applied to a product concept without having converged into a point-based solution yet. Instead, a range of possible configurations of parts, as well as a spectrum of acceptable design parameters for the parts included, have been prepared to make sure that multiple ways exist to derive products from the platform. The configurable product platform is modelled according to a specific technique that allows these ranges to be defined. These ranges can then be designed-to-order for different customer requirements, and the creation of derivative products is supported by a software architecture that integrates a number of analysis tools that calculate the most favorable configurations for a given set of requirements. A model of the development process and its support is presented in Figure 14.

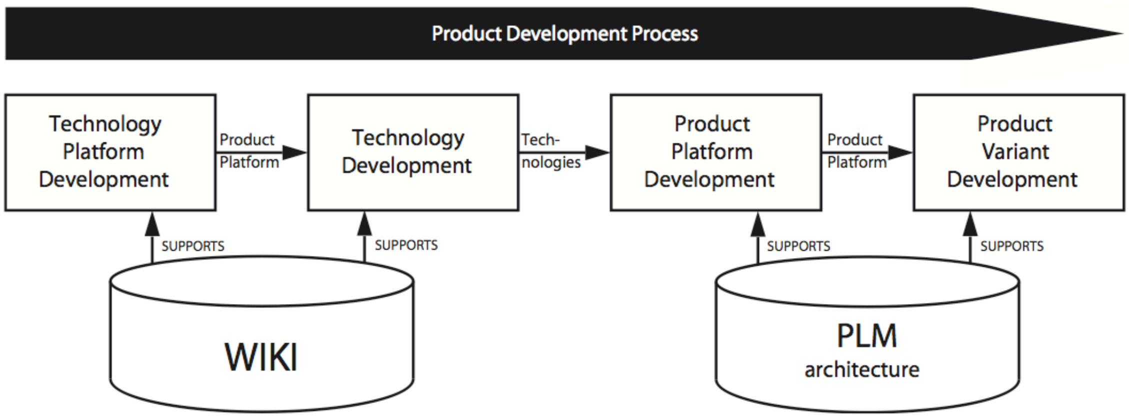

Figure 14. Process and platform support with the proposed approach.

This model is especially applicable to low-volume products with high demands of performance, the situation in which the case company finds itself. This company has a portfolio of similar products, but since the requirements for weight and performance are extremely high, there is little room for the compromises usually needed for creating platform products with predesigned parts. The technology-based configurable platform approach is applied to one of its products and shows how the modelling technique may be used together with analysis tools to quickly generate a number of derivative products, in addition to conducting a performance analysis.

The approach has significant implications for how to perform development work and document its results. Besides using the new modelling technique, it pushes companies to front-load their development and prepare for a number of combinations and requirements of the components and technologies used in the product concept. A major part of development focuses on generating knowledge and preparing alternative scenarios rather than creating a single solution, requiring large investments in early phases that may be leveraged at a later stage.

For the right type of products, a well prepared platform concept can provide a company with the opportunity to quickly find a suitable configuration to meet market demands with little need for redundant design work. The platform approach is also believed to provide an arena for discussing how development may be made more strategic by considering the reuse potential on a higher level in the organization. The technology-side of the platform provides an overview of competencies and facilitates the planning of products, as well as understanding the rationale behind the parameter boundaries in the configuration step.

Since it was mainly the result of other authors, the case presented about how a product may be quickly configured from a platform using the proposed modelling technique and software support will not be further discussed in this thesis.

4.5 Summary

Both managers and developers desire to improve the overview and accessibility of technological knowledge residing within a company. The current ways of accessing technological knowledge at a case company were explored, and the results showed that they typically used personal contacts to find information and gain access to knowledge. Reports were difficult to locate and comprehend, leading to barriers to reusing previous insights about how to apply technologies to problem-solving within product development activities. To integrate technologies into products, much more than technical information is needed, including preparations for manufacturing and estimates of costs and difficulties of closing knowledge gaps to apply technologies to new contexts.

A Wiki-based solution was developed for collecting information about technologies in a catalogue view, providing explanatory information, the status of development and links to detailed reports on technologies used within the company. The Wiki was demonstrated at the case company and received positive feedback, in addition to raising some concerns about the security and trustworthiness of the Wiki format. An integrated platform approach for improving the reuse of intangible technology and product-related assets was developed and tested on a sample product produced by the case company. The technology platform, mainly composed of the Wiki catalogue, was part of the approach. The integrated platform approach highlighted the need for new processes and practices to leverage a reuse strategy, with attention paid to early phases of development and new types of development projects to prepare technologies and product concepts for a range of different applications as opposed to point-based solutions.

The findings and proposed solutions are listed below in relation to their corresponding research questions.

RQ1: What are the barriers to efficient reuse of technologies within companies?

Findings from the case studies:

- It can be difficult to find information about technologies, partly because information is stored in project and product focused reports. Hence, to pan for reusable information, much context-specific text needs to be consulted.
- Technological knowledge is generated inside various departments and is possessed by experts that are not always easy to locate, especially for new employees. Without awareness about the existence of such knowledge within the company, there is a risk that this information may be easily overlooked, especially information that is cross-departmental or was developed a long time ago.
- Merely artifacts and documentation is not sufficient for the efficient application of a technology; there is also a need for the support of developers and experts who have been using the technology in order to build trust and contribute their tacit knowledge.

- Manufacturing technologies often require a vast amount of preparation before they can be employed to new products. Thus, technology readiness does not equal preparedness since implementation and foresight are needed for the timely reuse of such technologies.
- In late phases of development of a technology, there is a need for adapting it to the specific requirements of the application intended. The knowledge generated during this phase is less generic and reusable in other contexts, which may be difficult to discern when reviewing documentation for reusable elements of previous work conducted.

Main findings from the literature:

- There are major challenges in forecasting the flexibility of a technology; accordingly, extensive testing and experimentation may be necessary to know whether it is useful across a range of applications.
- Likewise, building a business case for investing in reusable technology requires calculations using uncertain estimates.

RQ2: How can a company expose its knowledge about technologies internally to increase its usefulness as an available resource?

Proposed solutions:

- To use a Wiki-based technology catalogue as an additional layer of information that is accessible and that provides an overview of how to find detailed information on technologies.
- To use readiness metrics for different applications to inform employees of the anticipated difficulties in applying a technology to certain contexts.
- 'Yellow Pages' information on experts who possess tacit knowledge on different technologies in the Wiki pages.
- To encourage input of information and lessons learned to the easily edited Wiki-format from various stakeholders within the company.

Feedback from the interviews:

- The Wiki prototype software received strongly positive feedback and was deemed useful for fulfilling a range of wishes regarding access to technological information.
- A concern was raised about the risk of information theft when collecting core technological information in an accessible way.
- There may be safety issues in connection with the Wiki-format, including inherent risks in making information available that has not yet been verified by an appointed expert responsible for the veracity of the data.
- Collecting a new generic type of information would require additional administration and resources, which adds to the already high costs and requirements associated with documentation.
- Since technologies evolve with continuous application and development, it is important, and may be difficult, to keep information up-to-date in the technology Wiki.
- Redundancy may become an issue when the same information needs to be accessible to those searching for products, as well as those looking for technologies.

From the literature:

- A culture of sharing information is important for successfully introducing collaborative knowledge repositories.
- There are several impediments to incentives for contributing information that are important to address to balance the costs of additional documentation.

RQ3: What are the opportunities for building support for technology reuse into product and technology development processes?

- A technology-based configurable platform approach can be introduced for reuse on multiple levels in the organization, with component reuse between products, concept reuse within and between product families, and technology reuse throughout the organization. An integrated approach would allow for managing the overlap and interfaces between these forms of reuse, which may eventually develop into a complex type of core competency for companies that become successful at this multi-tiered platform thinking.
- An explicit requirement can be imposed on projects to deliver generic results to the Wiki as a repository for technology information (develop for reuse).
- Building a culture and a process that encourages the search for previous knowledge before starting development (develop with reuse).
- The introduction of roles and organizational entities responsible for collecting, managing and displaying the technology information gathered will likely be important for working continuously with prioritizing the issue.
- In order to warrant prioritizations of long-term strategic objectives, the perspective of platform thinking for competencies and technologies should be addressed when planning and initiating technology development projects.

5 DISCUSSION

5.1 Agreement Between Findings and Literature

The empirical findings on the barriers to reuse align well with previous literature on the challenges of transferring knowledge and managing technologies, e.g. the need for enabling technologies before they are introduced in products (Eldred and McGrath, 1997a) and the problem of reusing knowledge documented in specific contexts (Levinthal and March, 1993). The issue of developing technologies with unclear goals was to a certain degree in conflict with the idea of developing generic assets to allow flexibility in their deployment. To have a separate technology stream from which products can be selected (Clausing, 1994) implies a process where the goals of technology development are not as tightly linked to products as in the roadmap depicted in Figure 6. However, the problems at the case company could be the result of a confusion about the objectives in those particular cases, and a misalignment between the expectations of the technology development team and product developers as discussed by Leonard-Barton (1988). Contrary to the proposal by Clausing (1994), it was not a case of a deliberate, systematic process of letting technologies mature independently of products. According to the TRL scale (Mankins, 1995), a target application is needed to progress beyond levels 3-4 and the 'technology stream' may thus be best suited to early phases of technology development.

The feedback on the Wiki-based technology catalogue rephrased a number of considerations also found in the literature, e.g. the issue of additional workload (Markus, 2001), as well as the importance of keeping information up-to-date and making it trustworthy (Watson and Hewett, 2006). The concerns regarding the risk of sensitive information spreading to competitors was not found in the literature, and neither was the issue of a redundancy between repositories for technology and product information. These issues may be embedded in the notion of accessible catalogues exposing core competencies, and may be worthy of further investigations.

5.2 Selection of Methods

Qualitative case studies allow close examination, provide rich information and are thus well suited for generating ideas and theories. This research started with an industrial need and idea notion of how to address this need by using the vague concept of technology platforms. The research called for clarifications and case studies allowing for both deeper insights into industrial contexts and inspiring thoughts approaching solutions for improved technology reuse. An established contact and access to previous empirical data played important roles in the selection of the case company. This choice facilitated practical matters during the research process and provided an understanding of the phenomenon from which the idea of the research originated. However, if more than one company had been studied, allowing comparisons to support the identification of unique and common features, the possibilities of testing for external validity would have been improved. VAC has been described as a company typical of the aero industry (Högman, 2011), which lends some support for generalizing the results to that industry. Additionally, during the course of this research, the findings and ideas have been discussed informally during meetings and workshops with companies in other industries. Many of those companies that like VAC develop and manufacture technologically advanced products recognize the issues relating to technology reuse and showed an interest in the solutions proposed. Hence, there are indications that results could be duplicated in studies at companies in other industries that feature characteristics similar to VAC.

The literature review reported in Paper B was intended to widen our perspectives and avoid biases towards the initial idea of platform development for achieving the benefits of improved technology reuse intended. Various research fields were included in the review and a spectrum of terminology was used in the search queries to find similar research studying relevant aspects and perspectives. It was clear that the topic of reuse is generic in nature and manifests itself in a variety of ways. Hence, due to a lack of awareness of alternative terms and concepts for which to search, it is likely that valuable literature might have been overlooked.

5.3 Reflections on the Research Process

The research activities covered in this thesis started with a detailed examination of technology information management at the case company. During the following phase of building theory made up of empirical data, an holistic perspective on the issue was sought and led to an exploration of the managerial and strategic aspects of technology reuse, which was reflected in a moderate change of research questions to cover generic topics rather than the specifics of presenting technology information.

Instead of choosing between a strategic or an operational level of study, the content of this research may be seen as a ‘T’-shaped investigation that encompasses both the holistic perspective (horizontal bar of the ‘T’-shape) and a deeper investigation of selected operational issues (vertical bar of the ‘T’). Consequently, two forms of integration reveal the principal opportunities for contributions to existing theory and practice. The first form is the integration of different aspects and fields of research along the horizontal axis that provides an holistic perspective on technology reuse. The other form is integration between the strategic and operational levels along the vertical axis, focusing on the means by which strategies can be put into practice to influence the way developers work. Papers A and C mainly cover the detailed level, whereas Papers B and D principally contribute a strategic and holistic lens.

5.4 Efforts Made to Improve Reliability and Validity

There were multiple observers at all interviews conducted at the case company, typically one person asking questions and the other taking notes. Open-ended questions were used to ensure that the concepts discussed, such as ‘technology’, conveyed the same meaning to interviewees and that all relevant and meaningful responses to questions were exhausted. The reliability of the results of these interviews was also strengthened by the fact that the analyses did not elicit any major discrepancies between the interpretations of the answers by the various observers.

The list below describes the extent to which the eight techniques proposed by Maxwell (2005) and described in Chapter 3 were used to strengthen research validity:

1. Long-term involvement has been a key element in this research, using the same case company in multiple studies and closely following previous research conducted on similar topics in the same setting.
2. Rich data has been gathered by interviewing different managerial parts within the organization and by using recordings and detailed transcripts of the answers.
3. Transcripts were validated by respondents after the interviews and workshops were held at the case company to discuss findings and proposed solutions.

4. Intervention has not been performed, something that would have significantly strengthened the validity of the solutions proposed. Such implementations correspond to the second descriptive stage of the framework (Figure 11) of Blessing and Chakrabarti (2009) and is a prominent candidate for future research in terms of implementing a technology Wiki pilot.
5. Search for disconfirming evidence has been performed through a broad literature review and a critical analysis of the match between the expressed and real needs of the case company. Also, the negative feedback from the demonstration of the Wiki has been reported and the issues anticipated during the implementation will be addressed in future research.
6. Triangulation was partly employed by asking a variety of stakeholders in the case company, and by interviewing them both before and after the demonstrator was illustrated to avoid biased answers. However, a more thorough examination of reports and other documentation would have deepened our understanding of the content of codified technological knowledge. Instead, statements by interviewees have been our primary source for drawing conclusions about the availability and accessibility of information, which may be subjective and not representative of the company as a whole.
7. Quasi-statistics have been used when reporting on findings from interviews, indicating whether an opinion was shared by a few or the majority of the respondents. Larger samples would have increased the validity of such findings.
8. Comparisons have not been used. However, they provide opportunities for testing the external validity in future studies, as well as examining the causal impact of implementing the proposed solutions by comparing the situation before and after such interventions.

5.5 Reflections on Validity of the Results

5.5.1 RQ1 – Barriers to technology reuse

In the second case study, the interviewers used both open-ended and closed questions, focusing primarily on information management. The rationale behind focusing on information management was based on indications based on previous studies at the case company that information management might be an important barrier to technology reuse. An unstructured interview methodology without a theme decided in advance by the interviewers might have revealed other barriers to technology reuse and thus a different answer to the first research question. However, literature, previous experience at the case company and logical reasoning indicate that knowledge management is a key element in motivating companies to reuse technological competence.

Specific barriers to reuse, such as the way in which reports are stored and indexed in repositories, are based on a single-case method and may not be generalizable to other settings. The company size and the strong policies on security and verification in the aerospace industry are likely to influence the types of barriers found. It is, however, reasonable to assume that these issues are shared with numerous other companies and that there are various contingencies that determine whether these barriers exist in a specific company. Hence, it is probable that the list of barriers may be extended by studying other cases, and that similar barriers may be found in many other firms.

5.5.2 RQ2 – Exposing technological knowledge

There is a strong prescriptive element inherent in the second and third research questions, for which the strongest validity test would be to evaluate an actual implementation in a representative setting. The Wiki-based catalogue for sharing and managing generic knowledge about technologies has not been implemented at the case company, partly due to the limitations of Wikis in small-scale implementations as they require a critical mass to become useful. Hence, without a large intervention at a case company, it would be impossible to achieve a representative environment for testing the support tool. Instead, a prototype was developed and shown during interviews to get feedback from intended users on how well it might support their work. Not only did a vast majority of them approve of the concept, but the positive reactions of some respondents led us to believe that the Wiki might be a promising tool for supporting a technology reuse strategy.

There are various other methods that can be used for sharing information about technologies, such as exhibitions, cross-functional teams, virtual or real discussion fora, expert hotlines and patent data, to name a few. The most frequently used source of technological knowledge at the case company was contact with colleagues, something that should not be overlooked when discussing the value of introducing new support tools. Instead, such personal contacts may present an opportunity for further improvement or be advised as a general recommendation to other companies. The findings may have influenced the development of support towards a format that complements existing carriers of information at the case company.

The topic of codification of technological knowledge is common in the literature, but there are few examples of how to actually represent it in a repository, suggesting that the need for such a format may be to some extent generalizable to other contexts and that there is no "silver bullet" that would quickly make the technology Wiki obsolete in the industrial and scientific communities. On the other hand, the Wiki should not be viewed as a silver bullet, but rather as a potential way of meeting some of the needs and requirements in the areas of the collection, management and presentation of technological information within a company.

5.5.3 RQ3 – Processes supporting technology reuse

The third research question has been addressed by thought experiments on how platform thinking for technologies would affect the organization and how it may be integrated into other processes. The proposed answer to RQ3 is built upon research about product platform development, technology platforms and core competencies. The validity of the propositions can be tested only by evaluating them in a representative case and in the absence of such a case, logical verification of the claims can instead be used. It is our strong belief that the solutions proposed in Paper D to integrate platform thinking in the development processes are plausible and logically sound. However, the extent to which they can be implemented as profitable trade-offs against the, largely unknown, implications of such drastic changes remains to be tested. To provide such validation is not within the scope of this research, and future contributions and evaluations of the platform development approach will, hopefully, be able to discern its value to intended users in competitive technology-intensive industries.

6 CONCLUSIONS

Technologies are visible on the agenda of top management, on the drawing boards of engineers and in the hands of production personnel. Decisions regarding planning, development and deployment are made in these settings, and new knowledge can be generated from various activities. This research has attempted to bring all of these perspectives together in order to holistically address existing challenges for effective and efficient reuse of technological knowledge.

The first research question inquired about the barriers that exist against efficient technology reuse. The answer provided by this thesis mainly concerned the difficulties of locating and deploying knowledge generated by previous development projects. Two other barriers related to the nature of technologies: the uncertainty of forecasting which technologies to develop for future reuse and the need for adapting them before introduction in new applications. Thus, knowledge management and strategic planning are two important areas to address when facing challenges to the reuse of technological knowledge.

The second research question was partly based on the answer to the first question and focused on how to expose knowledge on technologies within a company in order to stimulate reuse. Knowledge management intentionally adapted to the characteristics of technologies and their development was the answer, and some recommendations about how they may be designed were presented. Based on the fact that technological knowledge can continuously develop in different locations of a company, a centralized repository was proposed that would allow easy access and quick contributions. A prototype based on Wiki software was developed and demonstrated at a case company. The prototype received positive feedback and further testing will show whether the main challenges to its gaining momentum in terms of use and the risks of security and misinformation may be mitigated and overcome to realize anticipated benefits.

The third research question addressed the organization of development and how business processes might be adapted for technology reuse by means of an integrated approach to platform-based development. This approach features several levels of platform thinking to take advantage of different opportunities for reuse, of which the technology platform represents the widest and most generic level. The technology platform acts as a source of knowledge towards the development of products and product platforms, and as a recipient of generic technological information generated throughout the organization. This model of development for reuse has gained appreciation on a theoretical level among our industrial partners, but has yet to be tested in a live business setting.

7 FUTURE WORK

The work outlined in this thesis is mainly exploratory and has led to many new questions. The following questions provide a selection of starting points for conducting future research on technology reuse:

- What do other companies perceive to be the main barriers to efficient technology reuse?
- What dimensions should be addressed when estimating the reusability of technologies in new applications?
- What reusable elements of technological knowledge should be stored in a platform repository?
- How well suited is the Wiki format for collecting and exposing technology-related knowledge within a company?
- How can documentation for the purpose of reuse be added to existing practices in a resource-efficient manner?
- How does the need for systematic approaches to reuse technological knowledge differ between companies, e.g. based on their industry, role in the supply chain and size?
- How can the sharing of technological knowledge within a company be supported by a personalization strategy, i.e. through various forms of direct interaction between individuals?
- How can technological knowledge be reused across companies in alliances or within supply chains?

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