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Challenges in Reference System Management – Descriptive Model of Barriers using Research Results as Reference System Elements in Corporate Product Engineering

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Abstract

When engineering new products and systems, engineers take reference to already existing (socio-)technical systems or sub-systems to reduce development time and risk. These references can originate from e.g., previous products, competitors, nature, or research. Consolidated and linked to each other in a reference system, these references form the basis and starting point of the development as reference system elements. Especially research is a rich and potent source for reference system elements regarding knowledge and technologies on the edge in all disciplines. Using this source is a non-trivial process. Thus, it can often be neglected by many companies. The goal of this publication is the exploration of barriers and challenges arising when engineers want to use research results as reference system elements in corporate product engineering. Based on semi-structured interviews with experts from nine different companies, here we present a descriptive model that explains and sets barriers and challenges in context with different types of research results as well as the methods and approaches to gather them. E.g., the results show that often the lack of a description of the possible applications of research results is a barrier to perceiving their value. We anticipate our model to be a starting point for further research to improve the applicability of research results as reference system elements in corporate product engineering. Therefore, we intend to develop recommendations and guidelines for product engineers and researchers respectively to overcome the barriers and improve the representation of research results.

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Keywords: Knowledge Management; Technology Transfer; Research Industry Collaboration; Barriers; University Research; Reference System Management

1. Introduction

The competitive landscape of today is heavily reliant on innovations, successful new products. Technological leaders are constantly on the lookout for new innovations to stay ahead of the competition. Companies in general strive to grow their business and revenue. Apple Inc. is undeniably a very successful company. Their success is widely based on one innovation – the iPhone. One core function of this innovation is Siri. Today, approximately 500 million average customers use Siri, allowing them to command instructions or ask questions by speaking to their phones in a natural conversational tone [1]. In October 2011, Siri was introduced as a built-in headline feature of the Apple iPhone 4S [2].

However, the story of Siri started already in 1993 outside of Apple. The *first Siri* was developed in a research project by the American nonprofit scientific research institute SRI International. SRI led the *Cognitive Assistant that Learns and Organizes (CALO)* project within the *Personalized Assistant that Learns (PAL)* program of the US Defense Advanced Research Projects Agency (DARPA) [2]. At the time, the vision was to use technology to create a multi-modal, conversational way to interact with all of the world's information. It took another 17-18 years of development, but

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eventually, Siri arouse from the formerly research project to now affecting millions of people [3].

The story of Siri is one success story of technology transfer from a research project into a corporate product development project, which resulted in innovation. This example shows the potential that results of research projects can offer for companies. While the importance and potential of research results is acknowledged widely in academia and industry, it is also agreed that technology and knowledge transfer pose various challenges and barriers [4–7]. Thus, it took Siri decades to finally become a part of the iPhone and communicate with millions of people, too.

1.1. References in product engineering

Knowledge reuse is a core activity in product engineering. Therefore, new products are always a combination of new and successful old designs [8, 9]. Iyer et al. discovered that only 20% of the subsystems that were planned to be developed newly, actually have to be designed fundamentally new. Thus, 80% of the subsystems that were intended to be designed newly could be designed by taking over or modifying existing designs [10]. The main reasons for Design Reuse are a reduction of development costs and time as well as an increase in development flexibility [10, 11]. There are various approaches to describe the design process based on references such as Case-Based Reasoning [12] or C-K Theory [13].

Based on their observations, Albers et al. formulated the model of PGE – Product Generation Engineering [14]. With this model, they can describe any product development. Thus, this model provides a strong foundation for design research and the development of design supports. Hereby, the model of PGE is based on two basic assumptions. The first assumption is, that every product development is based on already existing (sub-)systems or concepts [14]. These elements serve as the starting point for the new development project. Albers et al. introduced the reference system to model these elements as reference system elements (RSE) [15]. The elements of this reference system are defined as "elements [that] originate from already existing or already planned socio-technical systems and the associated documentation and are the basis and starting point for the development of the new product generation" [15].

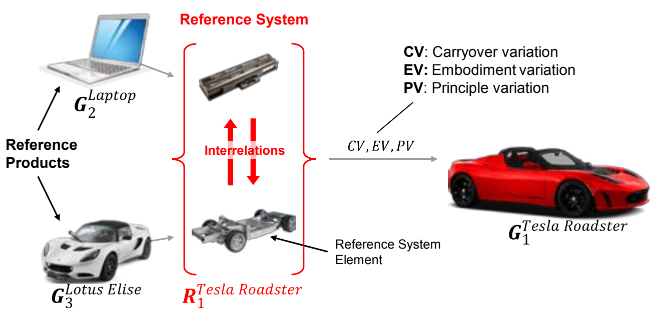


Fig. 1. The model of PGE describes product engineering as the development of a new product generation Gn based on the reference system Rn. New subsystems are developed by the three types of variation CV, EV, and PV. (based on [15])

As illustrated in Fig. 1, the model of PGE describes the development of a new product as the development of a new product generation G_n based on the respective reference system R_n [15]. G_n is then developed by three types of variation of the RSEs. These types of variation are carryover variation (CV), embodiment variation (EV), and principle variation (PV). This is the second basic assumption of the model of PGE [14]. In carryover variation, an RSE is carried over with adjustments in the interfaces to fit it into the new product generation. In embodiment variation, the embodiment of the RSE is changed to fit into the new product generation. And, in principle variation, the solution principle of the RSE is changed, too [14].

1.2. Sources of reference system elements

As described in the definition of the reference system, its elements can "originate from already existing or already planned socio-technical systems and the associated documentation" [15]. Probably the most important source for RSEs is the experience of the engineers as well as the projects known to them [16, 17]. Other typical sources can be, if available, direct predecessor product generations, competitor products, or elements and technologies from universities [15]. Hajialibeigi uses four classes to describe all sources of RSEs. These are the vertical class (supplier, private client, public client), horizontal class (competitors), societal class (consultants, government, private research institutes, professional associations), and specialized class (university, conference, scientific journal) [18].

As shown in Fig. 2 in the RSE identification atlas, I et al. provide a holistic view on the sources for RSEs as well as methods and tools to access these elements [19]. The atlas contains a total of 12 knowledge spaces which span over four different categories of knowledge spaces. RSEs can originate from the same branch, an other branch, research, or society/ nature. Depending on the accessibility for the corporate engineer these four categories are specified within the 12 knowledge spaces [19].

Research is a particularly interesting source for RSEs as it provides on-the-edge technology and knowledge. Thus, research is a valuable source to develop innovative products [4–6, 20, 21].

1.3. Barriers when using RSEs from research

Great challenges in using RSEs, in general, are to identify and manage the RSEs as well as extract information from these [8, 10, 17]. One focus in literature is placed on the investigation of barriers in university-industry collaboration [4, 20–22]. Bruneel et al. identified two types of barriers of university-industry collaboration. They call these two types "orientation-related barriers" and "transaction-related barriers". Hereby, orientation-related barriers summarize barriers that are related to e.g., conflicting goals of universities and companies whereas transaction-related barriers consider barriers such as intellectual property conflicts or university administration [22].

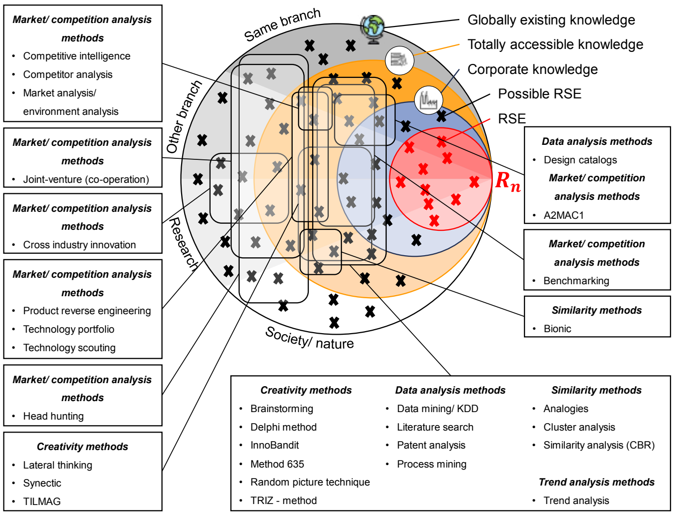


Fig. 2. The RSE identification atlas. RSEs can originate from 12 different knowledge spaces in total within the areas of the same branch, an other branch, research, or society/ nature. ([19])

Kleiner-Schaefer and Schaefer investigated company-internal barriers and barriers concerning regional innovation systems that complicate University-industry collaborations. They identified the lack of knowledge about opportunities for collaborations and too little financial support as the main barriers. Furthermore, they identified barriers related to the trust and matching skills of the collaborators [20].

While university-industry collaboration is an important approach to transferring knowledge and technology from research to companies, there are other approaches such as literature reviews, exhibitions, or conferences, too. These are neglected in terms of challenges in literature. Thus, it is our goal within this paper to explore the barriers that corporate engineers face when they intend to use RSE from research.

2. Research profile

2.1. Research goal and research questions

As demonstrated in the introduction example, research plays an important role in the development of new innovations as well as technological advancement in companies in general. The model of PGE already enables the description and modeling of the relations of RSEs from research and the system under development in a corporate environment. In the next step, we intend to support and enhance the technology and knowledge transfer from research into corporate product engineering. Therefore, we will develop recommendations for researchers, and politics/ funding agencies for the preparation of research results as well as guidelines for corporate engineers to use RSEs from research. Thus, our main goal of this paper is to research and explain the actual barriers and challenges that corporate engineers face when searching for RSEs in research and applying these in their engineering projects.

To reach this goal, we discuss the following research questions within this paper:

- What barriers and challenges do corporate engineers face when they are working with RSEs from research?
- How can the correlations between the identified barriers, and challenges and the methods, and approaches to gather the various RSEs from research be described?

Finally, we intend to provide a descriptive model that links barriers and challenges concerning different types of research results as well as the methods and approaches to gather them.

2.2. Research approach

To answer the research questions presented, we chose an interview-based approach. Therefore, we designed an interview guideline to conduct nine semi-structured interviews (compare [23]) with experts from corporate product engineering. After a brief general introduction to the topic of knowledge reuse in product engineering, we divided the interview guideline into two sections. We started with a broad scope on RSEs from various sources in the first section. In the second section, we focused on RSEs from research. We started both sections with a short introduction to set the stage and provide a common understanding of the necessary terms. To keep it simple, we used terms common in corporate practice (e.g., we avoided the term reference system element). Table 1, shows the nine interviews conducted with experts from different industrial sectors and engineering disciplines.

Table 1. Participants of semi-structured interview study.

No. of interview	Sector	Engineering discipline
I1	Automotive – Tier 1	Pre-development/ Innovation
I2	Materials	Material science/ Process engineering
I3	Technology	Simulation
I4	Automotive – software supplier	Process simulation
I5	Automotive – Tier 2	Product development
I6	Aerospace – Tier 1	Data analytics
I7	Automotive – OEM	Simulation
I8	Materials	Material science
I9	Machinery	Product development/ Data science

We utilized the freedom of semi-structured interviews, to adjust the order and focus on specific questions for the individual interviews. The one-hour interviews took place in an online setting. We followed a four-step process to process and analyze the interviews. After we audio-recorded the interviews, we used software to transcribe them. Subsequently, we anonymized the transcripts. In the following step, we used text and data analysis software to manually code the paragraphs of the interviews regarding three categories:

- Challenges and barriers that corporate engineers face when searching for RSEs in research and applying these in their engineering projects

- Methods and approaches to search and gather for RSEs in research and to apply these in engineering projects
- Different types of research results used as RSEs in corporate product engineering

The interviews were designed and conducted in course of the master thesis [24].

3. Barriers and challenges using research results as RSEs in corporate product engineering

In the following sections, we will present the results gained from the analysis of the interviews. First, we will present the methods and approaches followed by corporate engineers to search and gather RSEs from research. Second, we will list the different types of research results, that were considered as RSEs. Finally, we will display the barriers and challenges experienced by corporate engineers searching and applying RSEs from research.

3.1. Methods and approaches used by corporate engineers

We identified 16 methods and approaches to search and gather RSEs from research. As presented in table 2, we specified if the methods and approaches are primarily used to search for/ identify or apply RSEs from research.

Table 2. Methods and approaches followed by corporate engineers to search and/ or apply/ use RSEs from research.

Method/ approach to search RSE	Method/ approach to search and apply RSE	Method/ approach to apply/ use RSE
Participating (scientific) conferences (I2, I3, I4, I5, I6, I8, I9)	Financing/ supporting Ph.D. candidate/ doctoral researcher at research institutes (I1, I4)	Collaborative projects (publicly funded or direct cooperation) (I2, I3, I4, I5, I6, I7, I8, I9)
Attending fairs/ exhibitions (I2, I3)	Literature review (I1, I2, I3, I4, I5, I7, I9)	Hiring former researchers (I2, I3, I4, I5, I8, I9)
Organizing research pitches (I3, I6)	Employing Ph.D. candidate/ doctoral researcher (I1, I3, I9)	Contacting spin-off from research institutes (I3)
Personal networks (I3, I4, I5, I6, I9)	Direct conversation (I1, I3, I5, I6, I8, I9)	Hiring university graduates (I5, I9)
	Consulting expert as “translator” (I1)	Organizing internal lectures (I6)
	Offering cooperative master/ bachelor theses (I4, I5, I7)	Offering internships to students (I7)

3.2. Types of research results used as RSEs by corporate engineers

Based on the interviews we gathered the different types of research results used as RSEs and provided the examples given in the interviews in table 3.

Table 3. Types of research results used as RSEs by corporate engineers.

Type of research result	Provided examples	Interview
Human	Ph.D./ doctoral researcher, master, bachelor student, former researcher	I1, I3, I5, I6, I7, I9
Paper (journal, conference, etc.)	Code (e.g., simulation, optimization, models), simulation method, workflow, material model, process	I1, I2, I3, I4, I5, I6, I7
Experience/ Know-how	Experience and skills of experts	I1, I3, I5, I6, I7, I8
Presentation	On conference, in pitches	I2, I3
Demonstrator	Code (e.g., simulation, optimization, models), simulation method, workflow, material sample, material model, process, algorithms	I3, I5, I6, I7, I8, I9

3.3. Barriers and challenges experienced by corporate engineers

We identified 26 barriers and challenges that corporate engineers face when searching for RSEs in research and applying these in their engineering projects. We distinguished these barriers and challenges regarding their effect on the search for RSEs in research, their application/ usage of them in the corporate engineering project, or both. In the following, we present these barriers and challenges and provide a brief description.

Challenges and barriers to searching for RSE in research

Unclear use case/ application (I1, I4, I7): The possible use case or application of research results as RSEs in corporate engineering can be hard to perceive.

Unclear benefits profile (I1, I2, I4): The benefits of research results as RSEs for corporate engineering in terms of provider benefit, customer benefit, and user benefit can be unclear.

High amount of research results (I2): The high amount of different (/ alternative) research results available can be a barrier to identifying a suitable RSE from research.

Challenges and barriers to applying RSE from research

Neglected interdependencies of product and production (I1, I2, I6): Research results can be developed neglecting dependencies of e.g., technologies, materials, or (sub-)systems and the production process.

Unclear reliability/ maturity (I2, I3, I5, I6, I7, I8, I9): RSEs from research can require in-house validation.

Missing information (I2, I3): Research results can lack information on details (e.g., additives in materials) or boundary conditions (e.g., used simulation tool environment).

Lacking professionalism (I3): The tools, parts, or environment used for the research result might not fulfill professional standards.

Unfitting RSE environment (I3, I6, I7, I9): The tools, parts, or environment of the research result might not fit the available tools, parts, or environments (e.g., simulation environment but also in terms of human factors such as emotions, etc.) of the company.

Excessive positivity (I3): Published research results show what works well and can neglect to present limitations and failures.

High disciplinarity (I5, I9): Research results can be discipline/ sub-system specific neglecting interrelations to other disciplines and sub-systems.

Neglected systemic interrelations (I5, I6, I9): Research results can be sub-system specific and neglect interrelations and connections to other sub-systems.

High generality (I9): Research results can be on a general level where specifics are simplified (e.g., process models neglecting individual skill sets or motivation of engineers).

High time investment for implementation (I1, I7, I9): The search and implementation of RSEs from research can take more time compared to relying on the experience and knowledge of in-house technologies.

Difficult scalability (I1, I2, I5, I6): The scaling from a lab scale to a corporate scale can be a barrier to implementing RSEs from research.

Lacking technological/ scientific expertise of management (I6): The management in companies can lack in technological/ scientific expertise to realize the value of RSEs from research (e.g., especially if they are not engineers themselves).

High progressiveness (I5, I8): Research results can be too advanced for the current status of the company.

Unsatisfying intellectual property regulations (I1, I3, I4, I8): Research results can be freely available to everyone. This can complicate patentability and the advance to competitors. Furthermore, this can complicate the initiation of collaborative developments. On the other hand, research facilities can insist to keep all intellectual property. This can complicate the application.

Neglected profitability (I2, I6, I9): Profitability does not have to be a requirement of research results.

Long development time in research (I1, I2): Especially in cooperations, the duration of research projects to gain results can exceed the (available) time a company is willing to wait for results. The usual development time in research is three to five years compared to three to five months up to one or two years in companies.

Challenges and barriers to searching and applying RSE

Insufficient consideration of corporate needs (I1, I6, I7, I8, I9): There can be a mismatch to corporate needs when research results are generated without considering and analyzing these needs correctly.

Unattractive representation format (I1, I7): Research results can be represented in unattractive formats such as research papers. These require high mental effort to process, are monotonous, and do not fit the current way of processing information (e.g., few pictures and a lot of text in papers).

Unpopular research jargon (I1, I4, I6, I7): Researchers can use their research field-specific jargon to describe/ represent research results. This can increase the effort of corporate engineers to understand research results.

High specificity (I2, I5, I6): Research results can have a high specificity (e.g., regarding material processing). In this case, they just work for exactly one set of conditions (e.g., components and additives in a material system).

High rigidity of engineers and company (I1, I3, I5, I6, I8): The mindset, experience and knowledge of in-house technologies, and existing engineering environments (e.g., tools) can be a barrier to approaching or using RSEs from research (e.g., new knowledge, technologies, processes, or methods).

Missing expertise (I5, I6, I9): Corporate engineers can lack the expertise to understand (complex) research results (e.g., if they want to broaden their portfolio).

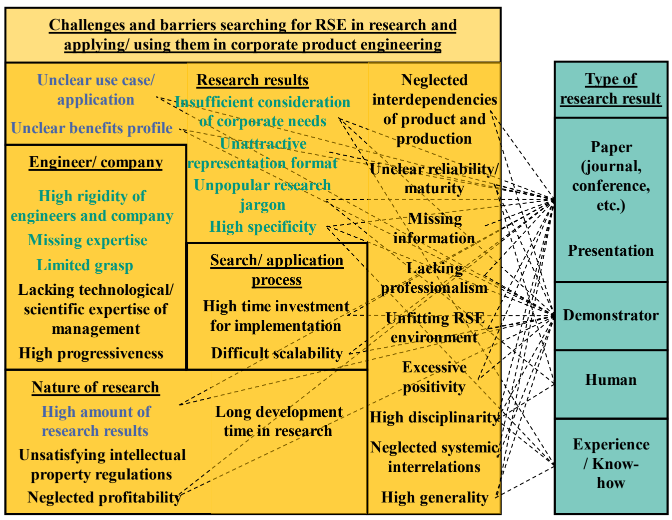
Limited grasp (I1): It can take too long to grasp the potential benefits profile of (complex) research results as RSEs.

Some of these challenges and barriers are related to each other such as the description of the use case/ application and the description of the benefits profile or the benefits profile and consideration of corporate needs. Furthermore, e.g., the limited grasp is related to the representation format and research jargon. But still, these are distinct challenges and barriers.

Additionally, we discovered, that some of the interviewees might not be aware of the diversity of research results that can be possible RSEs. These interviewees considered papers as the only format of research results.

4. Challenges in reference system management – descriptive model

In the following synthesis, we developed the descriptive model as presented in Fig. 3 based on the results.



Color code: Related to searching; Related to applying/ using; Related to both

Fig. 3. Modell of barriers and challenges in searching for RSEs in research and applying/ using them in corporate engineering projects. Barriers and challenges that are not linked to specific types of research results are general.

We distinguished four groups of barriers and challenges using research results as RSEs in corporate product engineering. Within the first group, we collected barriers and challenges that are related to the research result in itself. In the second group, we summarize all barriers and challenges that affect the process of searching RSEs in research or integrating these into the corporate engineering project. The third group considers barriers and challenges that are related to the corporate engineer and their company. Finally, in the fourth group, we collected the barriers and challenges concerning the nature of research. Within this model, we explain the possible relations of the different groups of challenges and barriers to specific methods or approaches to search for or apply RSEs from research as well as the various types of research results.

In the model, we linked the specific barriers and challenges to the different types of research results they affect. Interestingly, all challenges and barriers of the group engineer/ company are not specific to the type of research result, but of a general nature affecting all types of research results.

5. Conclusion and outlook

Concluding, we were able to identify four different groups of barriers and challenges that eighter affect searching for RSEs in research or using/ applying them in the corporate engineering project. The barriers and challenges affect different types of research results.

It should be noted, that the collected barriers and challenges can complicate the search/ identification of RSE in research or the application/ usage of them in corporate product engineering projects if present. Of course, the barriers and challenges are not always present. We are aware, that the presented model is not a conclusive description of all barriers and challenges but provides a metric that allows us to add further barriers and challenges when discovered. However, we believe that the selection of the interviewees from different industrial sectors and engineering disciplines allows us to gain a good initial version of the challenge and barriers model.

With this model, we intend to provide a basis for further research to finally support the usage of RSEs from research in corporate engineering projects. In the next step, we will investigate the different types of research results that can serve as RSE in corporate product engineering and situations in which these can be used. Based on these findings we will derive threefold recommendations to counter the identified challenges and barriers. These recommendations target researchers, corporate engineers, and funding agencies/ politics.

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