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Approaches, success factors, and barriers for technology transfer in software engineering—Results of a systematic literature review

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Abstract

Introduction: Technology transfer aims at supporting the transfer of results from software engineering research from academia to industrial application.

Objective: This paper reports on the current state of technology transfer in software engineering.

Method: We conducted a systematic literature review, in which we investigated 3070 papers. We identified in total 70 relevant papers, which were subject of a detailed analysis.

Results: Many different approaches are proposed to foster technology transfer in software engineering. The majority of these approaches suggest direct collaboration between industry and academia or teaching new technologies in industrial training or university education. In addition, a considerable number of experience reports on technology transfer exist. Hence, a multitude of best practices, success stories, and lessons learned is reported. Among others, empirical evidence, maturity, and adaptability of the technology seem important preconditions for successful transfer, while social and organizational factors seem important barriers to successful technology transfer.

Conclusion: Our findings can aid software engineering researchers in determining how best to support the transfer of their research results into practice. Furthermore, analysis of the literature also revealed that no reports exist on the combination of various technology transfer approaches, which could increase advantages of existing approaches while reducing their disadvantages.

KEYWORDS

software engineering, systematic literature review, technology transfer

1 | BACKGROUND AND MOTIVATION

Software engineering research aims at solving real-world problems (cf Wieringa[1]) and demands the evaluation of a proposed solution in an industrial setting (cf Basili[2] and Salman et al[3]). However, there is often still a gap between academic solution proposals and industrial needs, and for many results from software engineering research, it takes a long time to have an impact on software engineering practices.[4] This is not only due to the fact that novel results from academic research are often unknown to practitioners but also that those research results are often not directly applicable to industry.[5]

To close this gap, software engineering research also deals with technology transfer itself (cf Pfleeger[6]). Technology transfer aims at supporting the transfer of research results from academia to practice and is thus of interest to many scientific disciplines (cf, eg, Teece[7]). While some challenges remain the same regardless of the technology to be transferred, others are particular to the software engineering field, as software engineering technologies typically evolve in a short time and thus the state of the art constantly changes (cf Boehm[8] and Finkelstein and Kramer[9]).

There exists a plethora of proposed solution approaches to foster technology transfer in software engineering as well as experience reports on successful technology transfer projects. Nevertheless, there is a need to support researchers in identifying proper technology transfer approaches for their situation as well as best practices highlighting success factors and barriers for a successful technology transfer project.

1.1 | Related studies

Redwine and Riddle[4] examined how long it took for several technologies to become widely used in practice. They furthermore identified critical factors, inhibitors, and facilitators that influence this time length. Pfleeger[6] summarizes existing research on the matter of technology transfer in software engineering as of 1999. Placing particular emphasis on the collaboration between academia and industry, Pfleeger defines different ways of technology transfer and identifies inhibitors and promotors for the transfer of a technology to industry. Ivarsson and Gorschek[10] provide an overview of support for technology transfer in the requirements engineering field. To do so, they examined technology evaluations that had been published in the *Requirements Engineering Journal*. Geisler[11] proposes terms and definitions for technology transfer derived from existing research. Furthermore, objectives and research directions are defined to build a theory on technology transfer. In summary, there exist only few and dated secondary studies about technology transfer in software engineering; hence, there remains a need for evaluating recent technology transfer approaches in the software engineering field and providing guidance for software engineering researchers trying to transfer their results into practice based on success factors and barriers reported in the literature. As our results show, there exist several primary studies in the area of technology transfer providing contributions to software engineering research. Several papers propose approaches to improve the technology transfer in software engineering. For instance, Rombach and Achatz,[12] for example, propose a model for technology transfer consisting of various phases that support the transfer from concepts, techniques, and methods from academia and research institutions to consulting firms. Fowler and Levine[13] similarly present a model of a product's life cycle from its development to its decommissioning. A framework for technology transfer based on empirical research is presented by Shull et al.[14] Furthermore, several publications[15-18] discuss the role education plays in software engineering technology transfer. Also, several publications report experiences from one or more software engineering technology transfer projects. For example, Junker et al[19] report on transferring test methods in the finance sector. Fraser and Mancl[20] report on their experiences in introducing new telecommunication systems. Hinchey et al[21] report on the introduction of software assurance techniques, Zelkowitz[22] on the introduction of formal inspections, and Lindvall et al[23] on the introduction of tools in the space and aerospace domain.

1.2 | Contribution

To assess the current state of research for technology transfer in the software engineering field, this paper reports on the results of a systematic literature review. We discuss the proposed technology transfer approaches as well as success factors and barriers reported. Hence, this paper provides guidance for researchers seeking to disseminate their research results (eg, concepts, techniques, or methods) into practice. Furthermore, we identified research trends in the field of software engineering technology transfer and gaps in research, which need to be addressed in future. Through manual and automated search as well as follow-up snowballing, we identified 70 relevant papers. We investigated each paper in detail and extracted and synthesized the findings reported therein.

1.3 | Outline

The outline of the paper is based on well-established best practices for systematic literature reviews (cf other studies[24-26]). Hence, the paper is structured as follows: Section 2 introduces the research method used, hence reporting research goal and questions, as well as paper selection and classification. Subsequently, Section 3 presents our findings w.r.t. the defined research questions. Section 4 discusses the principal findings, threats to validity, and limitations of the study and points out future work. Finally, Section 5 concludes the paper.

2 | RESEARCH METHOD

We conducted a systematic literature review following the guidelines proposed by Kitchenham and Brereton.[26]

2.1 | Research questions

This literature review aims at identifying and synthesizing the published work on technology transfer from academia to industry in software engineering to gain insights into the current state of the field. Based on this goal, we defined four research questions, which are provided in Table 1.

First, as we want to identify the current state of the art, we investigate what type of research methods is reported. For instance, it is of interest whether solution proposals are commonly suggested or if more evaluations are reported. This can be seen as an indicator for the maturity of the field, eg, the lack of validation research would hint at an immature field. Second, we want to identify the state of the art regarding proposed technology transfer approaches, namely, what approaches have been suggested in literature and what are the commonalities between them, ie, can the individual approaches be grouped into general categories. Third, we want to determine the success factors for technology transfer. Hence, we synthesize the success factors reported in evaluation as well as in experience reports on technology transfer in software engineering. Finally, we want to do the same for the barriers for technology transfer; hence, we synthesize findings on which barriers have been reported in the literature.

Additionally, as commonly suggested (cf, eg, Kitchenham et al[24] and Petersen et al[25]), we report on results of some further questions regarding metadata on the reported transfers of technology as well as bibliometric data. This allows for better interpretation of the reported results and for identification of limitations of the literature review. Table 2 details the questions under investigation. As can be seen, questions are based on different investigation subjects. We analyzed the content of the included papers w.r.t. the types of technology transferred and the industry of recipients. Additionally, demographic data of the publications meta-information were analyzed.

2.2 | Paper selection strategy

We first manually searched a number of conference proceedings and journals for a limited number of years, thus establishing a set of papers that can serve as a quasi-gold standard for evaluating the quality of the automated search.[27] Based on our research questions and the papers found by manual search, we defined search strings for the automated search. We applied inclusion and exclusion criteria to the automatic search results and used the resulting set of papers as a starting point for a snowball search. The snowball search was conducted as a backward and forward search with as much iterations as were needed to arrive at a constant set of publications. Figure 1 outlines our search process.

2.2.1 | Manual search

As suggested in Kitchenham and Brereton[26] and Zhang et al,[27] we used the quasi-gold standard approach to identify relevant papers. The quasi-gold standard is established by manually searching a limited number of relevant venues for a limited number of years. Since our objective is to identify research on technology transfer in software engineering, we chose the following venues to be included in manual search:

TABLE 1 Research questions

Research question
• RQ1—type of research method What types of research methods are used for technology transfer in software engineering? For example, solution proposal and validation research?
• RQ2—type of proposed solution approaches What types of solution approaches are proposed to foster technology transfer in software engineering?
• RQ3—success factors What factors are reported to be of importance for successful technology transfer?
• RQ4—barriers What factors are reported to be barriers to successful technology transfer?

TABLE 2 Metadata questions

Subject of investigation	Question
Content	• RQ5.1—type of technology What types of technology are reported to be transferred in the papers? • RQ5.2—industry of recipients What industries are most commonly reported as recipients of technology transfer?
Publication	• RQ6.1—publication count by year How many papers about technology transfer are published each year in software engineering venues? • RQ6.2—top venues What are the main outlets for papers on technology transfer in software engineering?

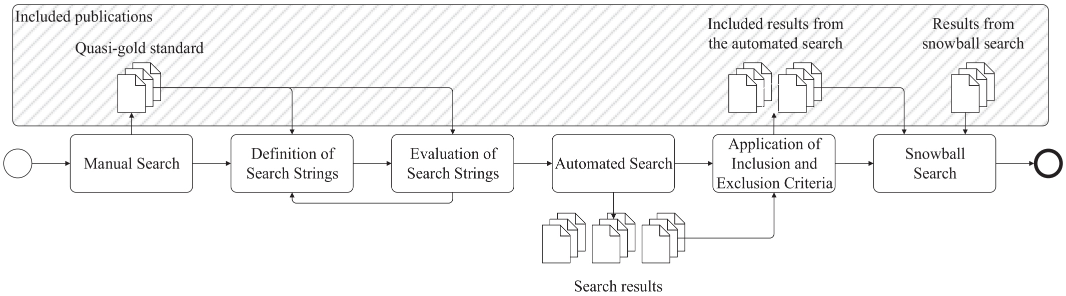

FIGURE 1 Overview of search strategy

- International Conference on Software Engineering
- Software Engineering Research and Industrial Practice
- Conducting Empirical Studies in Industry
- International Conference on Evaluation and Assessment in Software Engineering
- International Symposium on Empirical Software Engineering and Measurement

The manual search found 10 relevant papers for the years 2011-2015.

2.2.2 | Search string definition

Based on our research question and a word frequency analysis of titles, keywords, and abstracts from our manual search results, we developed several search strings for an automated search. We evaluated each search string's adequacy by performing an automated search limited to our chosen venues and time span and measuring the sensitivity (ie, the percentage of the papers found manually that was found by the automated search) and the precision (ie, the percentage of papers found by the automated search that were relevant). We finally settled on the search string: (transfer) AND (industry OR practice) AND (academia OR university OR research) AND ("software engineering"), which found 20 papers, eight of which matched the ones we found manually. Figure 2 illustrates the ratios between the relevant papers missed (light gray, ie, Rodríguez et al[28] and Sharp et al[29]), the relevant papers found (shaded, ie, previous studies[5,19,30-35]), and the irrelevant papers found (dark gray) by automated search for the search string and also the ratios between the quasi-gold standard (all papers found by manual search) and the (relevant and irrelevant) results from the automated search. With a sensitivity of 80% and a precision of 40% calculated based on the quasi-gold standard, this search string can be considered of optimal sensitivity and high precision as defined by Zhang et al.[27]

2.2.3 | Automated search

Our automated search, conducted in July 2017 in IEEE Xplore, ACM Digital Library, and Scopus, yielded 442 unique results and included all years. After applying the inclusion and exclusion criteria, 60 papers remained, including eight papers already selected by manual search. From these, 39 were initially found with the IEEE Xplore search, 17 with the ACM Digital Library and, 42 with Scopus. Considering duplicates found by multiple search engines, we ended up with 60 included papers. The inclusion and exclusion criteria were applied by two of the authors independently. Both initially agreed upon 41 papers to be included; for 60 papers, the two authors disagreed or were unsure about. After more detailed investigation of the full papers and discussions, we settled on 19 of these 60 papers to be included.

2.2.4 | Snowball search

In addition, we checked the references of the 62 papers found (52 of which were discovered exclusively through automated search, eight discovered through automated search as well as manual search, and two discovered exclusively through manual search) and papers citing these papers for further relevant papers. This first round yielded seven not yet included papers. Based on these seven papers, we found one more. A third round of snowball searching did not yield any new results. In the end, our final set consists of 70 included papers.

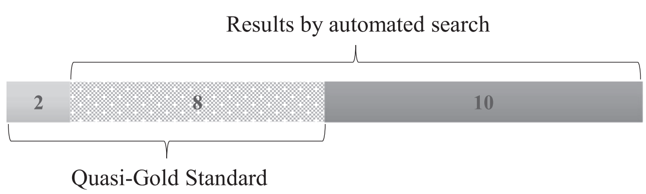

FIGURE 2 Relationship between quasi-gold standard and automated search results

2.3 | Inclusion and exclusion criteria

For the manual as well as for the automated search, we applied the following inclusion and exclusion criteria.

Inclusion:

- Published in a peer-reviewed journal or conference/workshop proceedings
- Focus on technology transfer from academia to industrial practice in software engineering

Exclusion:

- Not focused on technology transfer in software engineering (eg, focusing on academia industry collaboration in general)
- Not focused on technology transfer from academia to practice (eg, focusing on technology transfer between domains)
- Focus on summarizing existing research (eg, secondary studies)
- Introductory papers for special issues, conferences, or workshops
- Papers shorter than three pages
- Papers not written in English
- Full text not available online

2.4 | Data extraction and data synthesis

The data extraction phase was conducted collaboratively by the authors, and data pertaining to the research questions were recorded. Each paper has been classified independently by two researchers. In cases of disagreement, these were resolved by discussion. If no agreement could be reached, a third researcher was consulted. We used a combination of quantitative and qualitative synthesis approaches following the guidelines suggested by Kitchenham et al[24] and Cruzes and Dyba.[36] If applicable, we made use of accepted classifications.

To categorize the studies by research methods, we adopted the classification proposed in Wieringa et al,[37] as this classification scheme has frequently been used in systematic literature reviews to classify software engineering research (eg, Petersen et al[25] and Kitchenham and Brereton[26]). While the original classification scheme distinguishes between six types of research methods, in our case, only four categories are applicable. This is, for example, since technology transfer deals with the transfer into industry. Hence, there exists no academic validation research on questions of technology transfer but evaluation research in industrial practice. Table 3 introduces the categories used.

All papers that propose a solution approach (ie, papers that have been classified as evaluation research or as proposal of a solution) were further classified based on the solution approach they propose. Table 4 introduces the categories and subcategories derived from the solution approaches proposed.

All papers that do not merely propose a solution (ie, papers that have been classified evaluation research, opinion papers, or experience papers) were examined with respect to the technology transfer reported therein. To this end, we classified these papers according to the type of technology that is transferred and the industry that receives the technology. Regarding the type of technology transferred (Table 5), papers report either on the transfer of a product (eg, a development tool) from academia to industry or on the transfer of some kind of process. In this sense, a process can, among others, be an engineering principle such as model-based development or a certain modeling or analysis technique. In addition, some papers are either generic or do not provide sufficient detail to determine which type of technology is in focus; both are classified as "no particular reported."

For the recipient industries, a detailed classification scheme is given by Table 6. Again, papers that either did not provide sufficient detail to assess to which industry the technology has been transferred or state that the proposed solution is applicable to all industry domains are classified as "no particular."

For success factors and barriers, categories have been developed based on papers reporting similar success factors and barriers. When we analyzed the papers with respect to success factors and barriers, the relevant papers were read by two different researchers. Each of them

TABLE 3 Classification—research method

Type of research method	Description
Proposal of a solution	Proposes a solution approach and demonstrates why it is relevant without offering a sound validation.
Evaluation research	Examines a technique to foster technology transfer in practice.
Opinion papers	Report the personal opinions of the authors.
Experience papers	Report technology transfer experiences

TABLE 4 Classification—solution approach

Type of solution approach	Description (technology transfer is achieved by …)
Collaboration	… collaboration between academia and industry.
Project	… collaboration within projects.
Institution	… founding of a dedicated institution for technology transfer.
Empirical	… empirical investigations in industry.
Education	… educational approaches.
Student education	… teaching students techniques not yet widespread in practice.
Professional education	… teaching industry professionals techniques to be transferred.
Mediums	… approaches using specific mediums.
Development tools	… software tools that accompany the introduction of techniques into industrial practice.
Web based	… social networks, repositories, web portals, etc.
Other	…, eg, approaches suggesting different guidelines and other specific mediums.
Model/theory	… approaches aiming at defining some general model or theory on technology transfer.
Other	… other general approaches.

TABLE 5 Classification—transferred type of technology

Type of technology	Description
Product	The technology transferred is some kind of product (eg, a software tool).
Process	The technology transferred is some kind of process (eg, a certain approach for developing software).
No particular reported	Paper does not detail the type of technology transferred.

identified success factors and barriers mentioned in the paper and named them. In the second synthesis step, these success factors and barriers were discussed and consolidated. In the final synthesis step, the different success factors and barriers were clustered and grouped into categories. The final categories for success factors can be seen in Table 7 and for barriers in Table 8.

3 | RESULTS

This section reports the results of the systematic literature review. Therefore, the following subsections are structured according to the research questions. In total, 3070 papers have been investigated. After applying the inclusion and exclusion criteria, 70 papers were identified as relevant and thus were subject of a detailed investigation. For a complete list of relevant papers and their classification, please refer to Appendix A. For categorization according to RQ1 and RQ5, papers were read entirely and classified. To answer research question RQ6, the publication metadata were analyzed.

3.1 | Type of research method (RQ1)

To answer RQ1, the papers under investigation were classified according to the classification scheme for research methods proposed in Wieringa et al.[37] Figure 3 shows the detailed distribution of research methods used. About a quarter of the papers under investigation are

TABLE 6 Classification—recipient industries

Industry domain
Telecommunication
Health (eg, medical devices and pharmaceutical)
Space and aerospace
Finance (eg, bank and insurance)
Electronics
Automotive
Industry automation
Software development (eg, programming and web engineering)
Other embedded
No particular

TABLE 7 Success factors for technology transfer

Type of success factor	Count of mentionings
Technology-related	58
Practitioners involved in development	15
Evaluation	15
Adaptability	12
Addresses industry needs	7
Tool support	5
Adherence to standards	3
Long-term viability	1
Process-related	45
Training	8
Information flow	8
Researchers present	8
Cost-benefit/risk analysis	7
Appropriate mediums	6
Piloting	2
Long-term collaboration	2
Introduction to large parts/entire company	1
No strict deadlines	1
Clear roadmap	1
Risk management	1
Organization-related	24
Champion/advocate/broker	15
Commitment	5
Trust	2
Openness to change	1
Process integration	1

classified as proposal of a solution. These papers propose a solution approach for technology transfer and demonstrate why it is relevant without offering a thorough validation. Of the papers under investigation, 36% are categorized as evaluation research. These papers present an evaluation of a technology transfer approach in an industrial setting. Eleven percent of papers under investigation are considered opinion papers. These papers mostly report on the personal opinions of the author(s) about some aspect or aspects of technology transfer. And 29% of papers are experience papers. They report experiences the authors or their companies made during technology transfer. This does not mean that the other papers other than opinion papers or experience reports do not discuss on personal opinions or experiences made. As will be seen when discussing success factors and barriers also, proposals of a solution as well as evaluation research also give valuable insights that stem from experiences the authors made. However, according to the classification scheme,[37] the papers have been each assigned to the one category that describes the paper best.

The distribution shows that many solutions have been proposed as most of the evaluation research papers do also report on a proposed solution approach. In this case, the approach has undergone thorough evaluation in contrary to proposal of a solution papers. Furthermore, many experiences are out there, as evaluation research and experience papers give insight into experiences made during the application of technology transfer. We did only identify eight opinion papers. This is not surprising, as opinion papers are commonly less often published compared with other categories (cf, eg, Engström and Runeson[38] and Paternoster et al[39]). While we assume that authors of opinion papers do build their opinion on experiences previously made, these papers do not describe detailed experiences and lessons learned but place more emphasis on the authors feeling about technology transfer.

3.2 | Type of proposed solution approaches (RQ2)

All proposed solutions were further classified based on the solution approach they propose. Note that solution approaches are only proposed in papers classified as evaluation research or as proposal of a solution. Figure 4 shows the number of papers for the overall categories and provides a more fine-grained view on the different classes of proposed solution approaches with the respective numbers of papers for each class. Most proposed solutions for technology transfer deal with collaboration (33%). Also, a considerable number of education approaches have been proposed to foster technology transfer (26%). Twenty-one percent propose mediums (eg, guidelines, web pages, and repositories) to aid in technology transfer, and 14% propose a model or theory to better explain technology transfer.

TABLE 8 Barriers for technology transfer

Type of barrier	Count of mentionings
Technological	20
Immaturity (also missing scalability)	11
No or insufficient evaluation	8
Missing documentation	1
Organizational	13
Risk aversion	3
Lack of adaptability of existing infrastructure	2
Aversion to extensive training effort	2
Unrecognized needs/missed potential	2
Unawareness	2
Lack of involvement	1
Management overhead	1
Personal	9
"Not-invented-here" syndrome	4
Lack of objectiveness	2
Lack of experience	2
Anti-innovation attitude	1
Mismatch between industry and academia	27
Mismatch in cultures	13
Mismatch in expectations/needs/goals	6
Mismatch in vocabulary	5
Mismatch in information sources deemed important	2
Mismatch in defined measurements	1

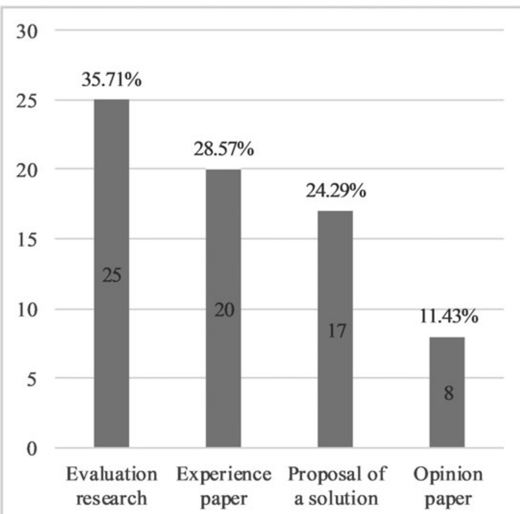

FIGURE 3 Distribution of research methods

Subsequently, we will outline some of the main solution approaches to technology transfer in software engineering with respect to their overall categorization.

3.2.1 | Collaboration approaches

A closer look at the more fine-grained categories reveals that most collaboration approaches deal with the introduction of technologies by an institution specifically established for fostering technology transfer. These institutions are often applied research institutes closely related to universities such as the Fraunhofer Institute[40] or the Software Engineering Institute.[13] These institutions primarily aid industry by providing support for administrative aspects of technology transfer.[41] This need is also reflected in the suggestion by Harrison[42] to employ some outsider as a mediator to bridge the gap between academia and industry.

Type of Solution Approach	
Collaboration	*14*
Project	1
Institution	9
Empirical	4
Education	*11*
Student education	6
Professional education	5
Mediums	*9*
Development tools	1
Web-based	5
Other	3
Model/theory	*6*
Other	*2*

FIGURE 4 Distribution of proposed solution approaches

Another form of collaboration is industry sponsoring of research activities, which, as Laird and Yang[34] point out, is only truly beneficial to researchers when it comes with close collaboration between academia and industry and is not just paid research. Other collaboration approaches propose conducting empirical investigations such as experiments as means for not only validation of research but also technology transfer itself (cf, eg, Baldassarre et al[43,44]). Conducting empirical investigations throughout the technology transfer allows for recognizing shortcomings early on and makes it possible to tailor the new technology to the company's needs. Kalinowski and Travassos[45] describe a successful transfer of such an empirical-based approach for introducing an approach for creating inspection plans.

Only Butler et al[46] propose using collaboration projects to achieve technology transfer. Regarding this finding, it is to mention that technology transfer in research projects seems to be common, as many experiences from projects are reported, but just this one paper proposes projects specifically as a solution for technology transfer.

3.2.2 | Education approaches

In the category of educational approaches, it can be recognized that about half of these papers suggest the long-term technology transfer by educating university students, who will transfer learned methods after finishing their studies. The students are considered change agents.[15,47] This reliance on students for transferring technologies is, however, criticized by Hallinan and Paul[16] who have concluded that the impact individual student can have is negligible. Several papers (eg, Chookittikul et al[17] and Abercrombie[47]) suggest the alignment of university curricula with industry to ensure relevancy. As a means for teaching complex methods, Michalik et al[18] propose the use of technical drama a three-step role play–based educational approach.

The other half deals with industrial training, ie, education of professionals to introduce a technology (eg, Lahdeniemi and Jaakkola[48] and Skevoulis[49]). As shown in a case study by Werner et al,[50] these education programs not only provide industry with better skilled staff but also provide researcher insight into industrial problems. Another education-based approach referred to as teaching company[51] is based on a cooperation between university and a company wherein students are recruited to work in industry alongside their studies, thereby acting as catalyst providing knowledge about new research results, learned at university, to the company. Abernethy et al[52] report on the use of guidebooks specifically designed to teach formal methods.

3.2.3 | Approaches using mediums

In the category of medium proposals to achieve technology transfer, one paper[53] proposes the use of development tools and five[54-58] suggest different web-based mediums. Approaches in the other medium category deal with writing guidelines[59] or the use of mediums in general.[33] As outlined by Grigoleit et al,[33] "A transfer medium can be any kind of communication medium used for transferring information from the transferor to the transferee."

3.2.4 | Approaches defining models for technology transfer

Using the dialectic method, Berniker[60] identified four models of technology transfer: The People-Mover Model, The Communication Model, The On-The-Shelf Model, and The Vendor Model. Moreover, there exist several models that describe the technology transfer process.[61-63] Even though the number of process steps varies slightly between these approaches, they all share a more or less extensive evaluation or validation phase aimed at ensuring the industrial success of the technology transferred.

3.2.5 | Other approaches

In other approaches, Cantu-Ortiz[64] presents a strategy for transferring expert system technology and Cecchet[65] suggests the release of prototypes as open-source software.

3.3 | Success factors (RQ3)

Looking at success factors for technology transfer reported in the literature, we can distinguish between success factors regarding (*a*) the technology to be transferred, (*b*) the transfer process, and (*c*) the receiving organization. In the following, we will first introduce the different success factor categories we retrieved from synthesizing the papers under investigation (Section 3.3.1) and second discuss the statements made in the publications under investigation for each of the three overall categories (Sections 3.3.2-3.3.4). However, many of the papers included in the study do not discuss success factors at all. Hence, these papers are not discussed in the following.

3.3.1 | Success factor categories retrieved from included papers

Papers were read, and success factors reported were identified and written down. Identified success factors were then aligned between the authors for each individual paper. Subsequently, the identified success factors were clustered and categories of success factors established. The categorization of success factors is given in Table 7. Next, we will outline the success factor categories defined and give a brief description what papers placed in the respective category typically announce as success factor.

Success factors regarding the technology to be transferred are as follows:

- Practitioners involved in development: The technology to be transferred is not developed by researchers alone, but practitioners are already involved in the development. This helps ensure relevancy and usability of the technology.
- Evaluation: The technology has not only just been developed but has also been scientifically evaluated. In particular, there are data that support the usefulness of the technology.
- Adaptability: The technology is not one-size-fits all but rather can be adapted. This means that the technology can be fitted to the users' needs, as opposed to the users having to adapt to the new technology. Furthermore, the technology can be adapted if users' needs change.
- Addresses industry needs: The technology solves a problem that actually exists in industry and that industry is concerned about.
- Tool support: There is tool support for the technology available that can be used by industry.
- Adherence to standards: The technology adheres to established standards.
- Long-term viability: The technology can be used and will be useful for a long time.

Success factors regarding the transfer process are as follows:

- Training: Users are trained with respect to how the technology should be used.
- Information flow: Information is exchanged between researchers that have developed the technology and users of the technology.
- Researchers present: Researchers (ie, people involved in the development of the technology) are present for the introduction of the new technology and can advise. It is particularly desired that researchers are available to answer questions about all technology or introduction related aspects.
- Cost-benefit/risk analysis: Before introducing the new technology, a cost-benefit or risk analysis has shown favorable results.
- Appropriate mediums: Appropriate medium for the transfer (ie, guidelines and workshops) are chosen to support the transfer of the technology.
- Piloting: The technology is first introduced as part of a pilot project, which typically involves the introduction of the technology in one or more company units in one or more development projects. This also helps in showing usefulness of the technology within the company.
- Long-term collaboration: The transfer is not seen as short-term project but as long-term collaboration between researchers and practitioners.
- Introduction to large parts/entire company: The technology is introduced to the entire company or at least to large parts as opposed to just small units.
- No strict deadlines: The transfer process accounts for unforeseeable events and does not impose strict deadlines.
- Clear roadmap: A clear roadmap for the technology transfer is established and followed.
- Risk management: During transfer risk management is conducted.

Success factors regarding the receiving organization are as follows:

- Champion/advocate/broker: There is someone tasked with championing the new technology.
- Commitment: The company (ie, the management in charge) is committed to the introduction of the new technology.
- Trust: The level of trust in the company is high enough so that the introduction of the new technology is not seen as a threat.
- Openness to change: The company is willing to change in order to use the new technology.
- Process integration: The company's processes allow for the integration of the new technology.

3.3.2 | Success factors regarding the technology to be transferred

Duarte[32] and Curran[15] discuss the importance of the maturity of the technology to be transferred, as premature transfer of new technologies can lead to unsatisfied users that are unlikely to give the same technology another chance even after improvements have been made. Another critical factor for technology to be transferred into industry is the existence of evidence about its benefits.[43,44] As can be seen in Table 7, this sentiment is shared by many authors. From a researcher's point of view, the need for evaluation can prove quite problematic as it is difficult to find companies that are willing to take on the risk of evaluating brand new technology. In several publications,[46,66,67] the authors highlight the need of technology to be adaptable as precondition for successful transfer into industry. A study by Jedlitschka et al[68] investigated the technology transfer of software inspection methods. It showed that in this case industry deems the impact the inspection methods will have on the product developed are more important than on estimated economic values. Particularly, increasing product quality (ie, delivering products that are a better fit for stakeholder intentions and are less error prone) and decreasing development time are seen as more important arguments for introducing the technology (ie, inspection methods) than an estimated return of investment. Also, the conformity to standards was not seen as strong argument. Furthermore, many authors recognized the need to have practitioners involved in the development of the new technology (eg, previous studies[51,65,69,70]), in particular to ensure that a newly developed technology addresses actual needs of industry (eg, other studies[40,48,71]). Also mentioned albeit in fewer publications were the need for tool support, the adherence to standards and frameworks (such as the Unified Modeling Language[16]), and ensuring that new technology remains viable over the long run.[65]

3.3.3 | Success factors regarding the transfer process

As for how the transfer of technology takes place, the way researchers and industry collaborate[46] and communicate[72] (ie, how information flows from researchers to practitioners) is considered to have a crucial impact on the successful transfer. Many publications stress the need of having someone who developed the technology (ie, a researcher) present for the introduction of a new technology (eg, present studies[22,63,69]). However, Smith et al[73] suggest using insiders to introduce new technologies as this has shown to increase acceptance compared with using researchers or other outside experts that introduce a new technology. Training practitioners to use the new technology is also a frequently mentioned factor for successful transfer (eg, Abernethy et al[52] and Mubeen et al[74]). Therefore, the importance of workshops and meetings to introduce new technologies to software developers is stressed in Diebold and Vetrò[31] and Jedlitschka et al.[68] Another frequently mentioned aspect is positive results from cost-benefit or risk analyses. Another important factor is the way the transfer takes place, ie, by which medium (eg, other studies[31,33,75]). In particular, scientific publications, which are often seen as difficult to comprehend by industry,[35] are criticized as unsuitable.

3.3.4 | Success factors regarding the receiving organization

Since introducing a new technology disrupts existing practices, it is of importance for organizations to possess enough qualified staff that can handle using the new technology and issues that will arise.[32] The need for adequate personnel is widely mentioned in many papers. Many publications stress the need of having someone who is in charge of the technology transfer, often referred to as champion, advocate, or broker (eg, literature[13,46,64,76]). For instance, it is sometimes advised that the personnel should be employed in-house (eg, Butler et al[46]). Other papers focus on the fact that there must be someone in charge, having the authority for introducing the new technology (eg, Bass[76]). Other papers emphasize the need for champions or advocates advertising the new technology within the company (eg, Cantu-Ortiz[64]) or for a broker who allows choosing an adequate technology to be transferred (eg, Harrison[42]). Another important factor reported by Buxton and Malcolm[61] is management commitment, which is needed to keep organizations from falling back on their established way of business.

Table 7 provides an overview of success factors mentioned in the literature along with their frequencies. For a complete classification of success factors for each included paper, please refer to Appendix A.

3.4 | Barriers (RQ4)

For the barriers for technology transfer reported in the literature, we also defined categories synthesized from the papers under investigation. Section 3.4.1 will introduce these categories and provide a brief description of the identified barriers for technology transfer. Subsequently, Section 3.4.2 will elaborate on the found barriers and give examples from the papers under investigation.

3.4.1 | Barrier categories retrieved from included papers

We identified four overall categories for technology transfer barriers. There exist barriers regarding the technology to be transferred, barriers regarding the receiving organization, barriers regarding personal interests, and barriers regarding mismatches between industry and academia. The categorizations for barriers are given by Table 8. Next, we will outline the barrier categories defined and give a brief description what papers placed in the respective category typically announce as barriers.

Barriers regarding the technology to be transferred are the following:

- Immaturity (also missing scalability): The new technology is not mature enough to be useful in industry. For example, it does not scale to practice.
- No or insufficient evaluation: There is no evaluation of the new technology or the existing evaluation is insufficient, so that its benefits cannot be assessed.
- Missing documentation: The new technology is not documented well enough to allow industry to use it.

Barriers regarding the receiving organization are the following:

- Risk aversion: The company tries to avoid any risks, which hinders the introduction of new technology.
- Lack of adaptability of existing infrastructure: The company's existing infrastructure is incapable of adapting to a new technology.
- Aversion to extensive training effort: The company does not want to invest in the training employees would need to use a new technology. Investment does not necessarily refer to monetary investment. Common is the aversion to giving employees time for their training to avoid unproductiveness.
- Unrecognized needs/missed potential: The company is unaware of its needs and does not see the potential of a new technology.
- Unawareness: The company does not know that the technology exists.
- Lack of involvement: Either employees or the management does not sufficiently involve themselves to the introduction of a new technology. This often results from a lack of commitment from the person in charge.
- Management overhead: The introduction of a new technology causes too much management overhead to be beneficial.

Barriers regarding personal interests are the following:

- “Not-invented-here” syndrome: Practitioners do not like working with technologies that were developed by someone that is not part of their organization.
- Lack of objectiveness: Practitioners do not judge the new technology fairly.
- Lack of experience: Practitioners are not experienced enough to use the technology.
- Anti-innovation attitude: Practitioners do not like new ways.

Barriers regarding mismatches between industry and academia are the following:

- Mismatch in cultures: The company's culture is too different from that of the researchers.
- Mismatch in expectations/needs/goals: Companies and researchers have different expectation, needs, and goals when it comes to technology transfer, so that they consider different things as important.
- Mismatch in vocabulary: Companies and researchers do not understand each other.
- Mismatch in information sources deemed important: Researchers are awarded for publications in research outlets not in trade journals, whereas practitioners avoid reading scientific publications.
- Mismatch in defined measurements: Practitioners define measurements for estimating when a technology is useful for them. Researchers commonly define different measurements (eg, objective criteria for evaluation of the technology). Different measurements from industry and academia are often misinterpreted by each other.

3.4.2 | Barriers for technology transfer

When it comes to barriers for successful technology transfer reported in the software engineering literature, there seems to be much more focus on issues concerning the mismatch of perceptions between academia and industry than on concrete technological issues. Two exceptions to this are Curran[15] who reports on a transfer of a circuit simulation program that received mixed reviews by industry and Selic[5] who criticizes the attention to functionality of new technologies at the expense of quality properties that seriously reduces their benefit to industry.

More common are reports on barriers caused by cultural and social issues (eg, previous studies[41,49,73,77]) such as collaboration projects between research and industry that involve too many people with too divergent goals and agendas. Buxton and Malcolm[61] report among others on the lack of awareness of new technologies prevalent in industry. Furthermore, in industry, there often exists an inability to change[61] that goes hand in hand with a lack of knowledge needed to work with new technologies.[73]

Another factor that hampers widespread technology transfer is business interests by industry partners involved in research projects, who are usually reluctant to have competitors access to information about successful new technologies and sometimes hinder researchers from publishing results obtained in collaboration.[34,41]

Having a closer look at the barriers reported, cultural and social issues cannot be blamed on the receiving organization alone. While this is the case for some factors, other relate to personal attitudes of core employees, or even more often on a mismatch between industry and academia. Specifically, a mismatch between industry and academia in expectations, goals, and needs as well as more general in different cultures is reported (eg, other studies[12,41,42]). This means, for instance, that industry assumes that academia was interested in providing a technology, which optimally fits and does not need any company-specific adaptations. Often mentioned is the mismatch in openness: Industry considers academia to be too willingly giving information to competitors and, hence, does not disclose all materials needed to researchers. Industry, on the other hand, is often found to be not open at all, meaning that industry is not interested in what others do and what generally exists in the field to solve a problem.

Table 8 shows the distribution of the identified barriers for technology transfer. For a complete classification of barriers for each included paper, please refer to Appendix A.

3.5 | Type of technology (RQ5.1) and industry of recipients (RQ5.2)

We further analyzed all evaluations, opinion papers, and experience papers with respect to the technology or technologies transferred and the recipient industries. In 11 of the 53 investigated reports, a concrete product is transferred. A product transferred is, for example, a tool to support software development or a network monitor and analyzer. As can be seen in Figure 5, most papers report on the technology transfer of a process (ie, a methodological concept to develop software). Papers report, for instance, the transfer of model-based software development, formal methods, safety analysis techniques, modeling techniques, or test methods. Two papers report on the transfer of a product and a process, while 14 papers did not mention which particular technology was transferred.

The most popular recipient industries can be seen in Figure 6. Papers reporting on the transfer into more than one particular industry were categorized accordingly. Again, some papers did either not provide sufficient detail to assess to which industry the technology has been transferred or assume that the proposed solution is applicable to all industry domains; these papers have been classified as "no particular."

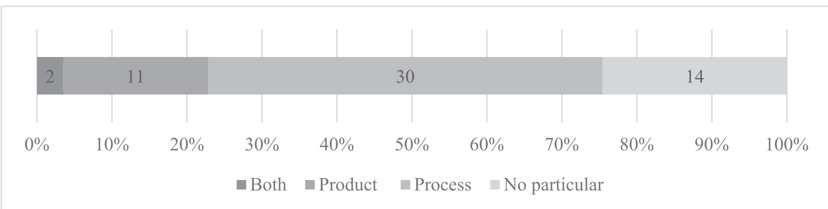

FIGURE 5 Reported technologies transferred

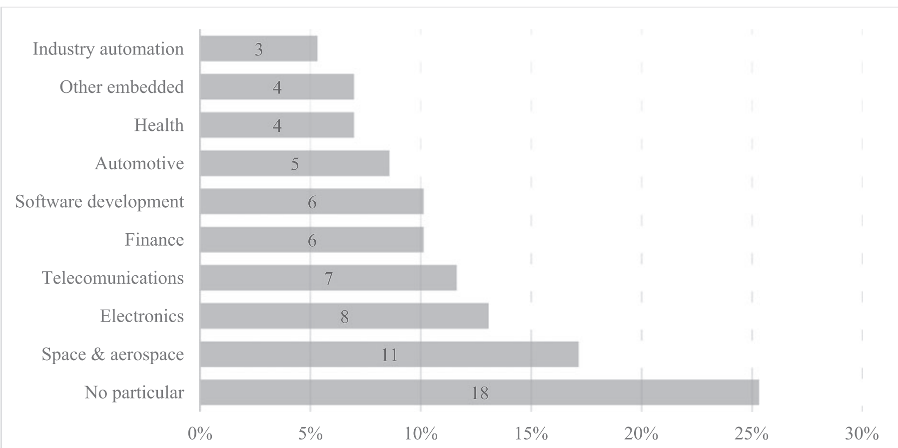

FIGURE 6 Reported recipient industries of technology transfer

Regarding the recipients reported, no clear trend is recognizable. Technology transfer reports describe technology transfer in various domains. As can be seen in Figure 6, most papers, which discuss the transfer into one concrete domain, report on experiences in the space and aerospace industry. It is to note that many experience reports originate from the same organization, namely, from NASA. Hence, the high number in this category does not represent many different companies, but several reports from the same company.

A look at the combination of reported recipient industry and the reported technology transferred also indicates a wide distribution. As can be seen from Figure 7, products and processes are transferred to all industries. There is no industry that only transfers either processes or products. Hence, it can be assumed that the types of technology transferred are comparable between the different industries as all industries have a need to transfer processes and products.

3.6 | Publication count by year (RQ6.1) and top venues (RQ6.2)

Investigating the publication count by year reveals that papers about technology transfer in software engineering started being regularly published in 1990. Since then, there has been some fluctuation in the number of papers published each year. Technology transfer in software engineering seems to have been of particular interest between 1992 and 2000 as well as from 2004 on. Lately, the topic seems to have gotten even more popular. The low number for the years 2016 and 2017 might be due to not all papers from these years being published yet. The annual publication volume of technology transfer research in software engineering is depicted in Figure 8.

Regarding the question of top venues for technology transfer in software engineering, the distribution of publications across different venues indicates that there are some venues more popular for technology transfer, but there is no absolute top venue. Table 9 shows the 10 most popular publication venues, as determined by the number of publications. As can be seen, most venues count fewer than four publications.

4 | DISCUSSION

Section 4.1 summarizes the principle findings of the reported results. Section 4.2 uses these findings to derive best practices for successful technology transfer and discusses how currently proposed solution approaches can aid in fulfilling these best practices. After the discussion of the threats to validity in Section 4.3, Section 4.4 discusses the implications for future work.

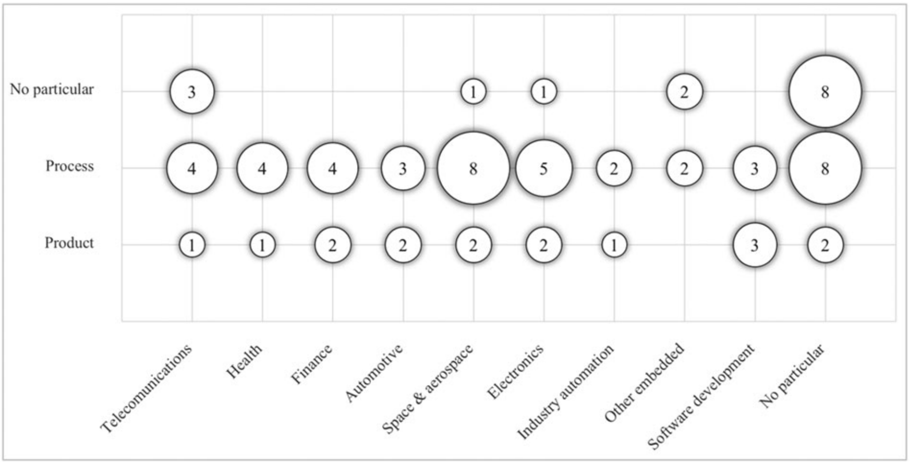

FIGURE 7 Transferred technology and recipient industry

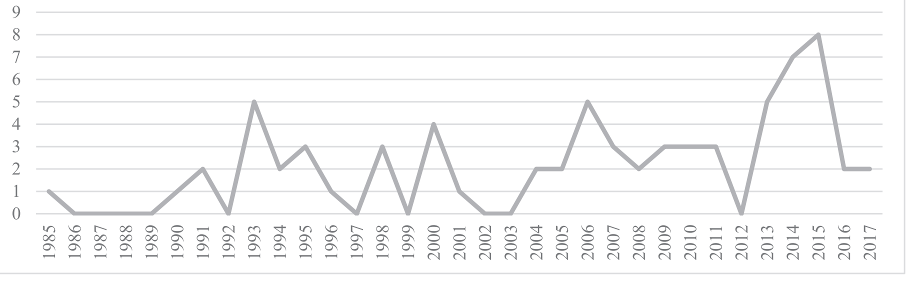

FIGURE 8 Annual publication volume

TABLE 9 Top venues

Venue	Abbreviation	Publication
International Workshop on SE Research and Industrial Practice	SER&IP	9
International Conference on Software Engineering	ICSE	6
International Symposium on Empirical SE and Measurement	ESEM	5
IEEE Conference on SE Education and Training	CSEET	3
University/Government/Industry Microelectronics Symposium	UGIM	3
International Workshop on Technology Transfer in SE	TT	3
International Workshop on Conducting Empirical Studies in Industry	CESI	2
IEEE Software		2
International Conference on Management of Innovation and Technology	ICMIT	2
Hawaii International Conference on System Sciences	HICSS	2

4.1 | Principal findings

In this paper, we reported on findings from a systematic literature review on technology transfer in software engineering research. Summing up, findings regarding the four major research questions from Table 1 indicate the following:

- There exists a multitude of proposed solution approaches as well as published experience reports and case studies, discussing individual findings from technology transfer efforts, indicating some maturity in the field of technology transfer. Nevertheless, as the related work shows, they have so far not been thoroughly investigated by secondary studies (*RQ1*).
- There exist several different approaches to foster technology transfer. The majority of these approaches suggest some kind of industry/academia collaboration or education approach to support technology transfer (*RQ2*).
- There are several success factors reported in the papers included in this study. For successful technology transfer, the technology to be transferred must be mature and adaptable to a certain degree. Furthermore, there must exist empirical evidence in favor of the technology. The transfer itself must be accompanied by close collaboration on a personal level. Lastly, there needs to be qualified personnel within the organization introducing the new technology as well as sufficient commitment by management (*RQ3*).
- There are several barriers for successful technology transfer reported on. In particular, it is often stressed that a mismatch in culture as well as expectations and goals of researchers and practitioners involved impedes successful technology transfer. For example, a too rigid protection of intellectual property by the introducing company typically leads to unfruitful collaboration and, hence, to failure. Furthermore, immaturity of the technology to be transferred and lack of evidence regarding the maturity are frequently mentioned barriers to technology transfer in software engineering (*RQ4*).

Furthermore, we reported on some findings regarding technology transfer practices in software engineering. It can be stated that the transfer of software products as well as the transfer of processes to aid the development of software is covered. In comparison, the transfer of processes is far more often reported and can hence be seen as more important to the software engineering field.

Technology transfer is applicable and of interest to a wide variety of industry domains and not limited to just some areas. This goes hand in hand with publications on technology transfer in software engineering being published in a variety of venues with no clearly most popular venue, indicating that the need for technology transfer is not limited to certain areas of the software engineering field.

Finally, it can be recognized that there exists a gap in the literature on technology transfer in software engineering: While there exist many solution approaches as well as experience reports and case studies, no investigations of combined approaches exist. For example, an approach combining the need to provide empirical evidence as foundation, industrial training to transfer knowledge and qualify industrial personnel, and close industry collaboration to monitor and apply a new technology could address all success factors and, hence, improve technology transfer. However, there is a lack of proposed combined solution approaches as well as a lack of experiences reported on such combined introductions.

4.2 | Interpretation of findings

A closer look at barriers and success factors for technology transfer reveals that both are closely related. Based on these findings, best practices on what to consider for a successful technology transfer project can be synthesized. Therefore, we will differentiate between preconditions a technology must fulfill, organizational and personal attitudes that support technology transfer, and best practices for the transfer process itself.

- Technological preconditions. First, there needs to be some preconditions the technology to be transferred must fulfill. The technology to be transferred must be mature, sufficiently evaluated, and well documented. Furthermore, the technology must directly address industry needs and must be adaptable, so it can be specifically tailored to industry purposes and later on adapted to changing industry needs for long-term viability. The technology shall adhere to standards and ensure for long-term viability. To support these points and to foster acceptance of the technology by practitioners, it is of vital important that practitioners have already been involved during development of the technology. Furthermore, the infrastructure of the receiving organization must be adaptable for integration of the new technology.

- Needed attitudes. To support successful technology transfer, there is a need for certain organizational and personal attitudes to be present in the company the technology shall be introduced. Hence, if these are not available, action should be taken to change the organization's culture to a more welcoming attitude for the introduction of new technologies. Employees and particularly the personnel in charge should be involved and committed to the introduction of the new technology. The organization's culture should place emphasis on risk management but not be risk aversive. Extensive training should be seen as welcoming opportunity, not as a threat. Involved personnel should be objective and experienced; furthermore, they should be open to new ways instead of having an anti-innovative and restrictive attitude towards technology not invented by themselves.
- Transfer process. To allow for a successful technology transfer, the transfer process must be supported by a champion employed to ensure successful technology transfer. The introduction is accompanied by training of employees. Appropriate mediums to foster technology transfer have been defined. A sufficient information flow on the new technology is ensured. Particularly, researchers who invented the technology are present during its introduction and available to the involved personnel. The technology should prove useful during pilot projects but thereafter been introduced to the whole company to avoid technological breaks and information gaps between different company units. There should be a clear roadmap; however, there should be not strict deadlines to account for the unforeseeable. The transfer process is accompanied by close collaboration between industry and academia to avoid problems stemming from the mismatch of cultures, expectations, needs, and vocabulary.

Comparing these best practices with the identified approaches proposed gives insight in how technology transfer can already be supported and what is still missing. In literature, a variety of collaboration approaches have been proposed. These approaches can aid in aligning industry's and academia's cultures and raising awareness for the pain points of the others. Such collaboration approaches can aid in the development of technology, as participation of practitioners is ensured and also in the introduction of the technology as participation of researchers is ensured. In addition, education approaches have been proposed; these address either the long term (ie, student education at the university level), which supports the need for experienced and educated personnel, or the short term (ie, industrial training), which is needed to accompany the introduction of a new technology. Other approaches dealing with transfer mediums can support the introduction of new technology as specifically defined mediums to introduce the new technology are a vital aspect. Regarding the needs for evaluated technology and mature technology, approaches for conducting empirical studies in industry and for measuring technology acceptance and maturity have been proposed. Although these approaches are not specifically designed to foster technology transfer, they can be used to support these important aspects of successful technology transfer. However, shortcomings in the current state of the art can be identified. There exists no approach or report of technology transfer projects that uses a combination of these approaches to address all aspects of successful technology transfer.

4.3 | Threats to validity

The main threats to validity in literature reviews are selection bias and inaccuracy in data extraction. Selection bias refers to publications being incorrectly included or excluded. To alleviate this threat, a systematic search process with explicitly defined inclusion and exclusion criteria was used. Making assumptions while reading a paper can lead to inaccuracy in data extraction. Therefore, only the information provided in the paper itself was used, but of course, a threat resulting from misinterpretation of information remains. To reduce this threat, we also applied the common strategy to have two researchers conduct the classification each researcher independently first and subsequently derived the final classification in discussions.

A remaining threat results from the sources used for search string definition and evaluation. In particular, the high precision in the gold standard can possibly indicate a too narrow search string even though optimal sensitivity indicates otherwise. But of course, the limitation to software engineering might lead to not detecting papers from closely related disciplines or from subdisciplines of software engineering. To cope with this issue, we conducted a snowball search using the included publications as the starting point.

Furthermore, it must be considered that we only aimed at identifying works that deal with technology transfer from academia to industry. Beyond those, there exists a multitude of papers dealing with technology transfer between domains, between companies, etc. These proposed techniques might also be applicable to technology transfer between academia and industry. Additionally, we excluded papers not explicitly stating that they aim at technology transfer. These papers might nevertheless still provide valuable contributions to the field.

Another threat remains in the selection of academic venues in general, as intellectual property protection might inhibit publishing reports of technology transfer. Hence, we assume that there is more technology transfer conducted than reported. However, as included papers typically anonymize the companies involved, we, thus, assume that the reports are a realistic sketch of the state of the art. Technology transfer seems to be a very product and situation specific issue, as many reported barriers and success factors are individual and not necessarily generalizable. Nevertheless, as shown in Section 3, some barriers and success factors are reported again and again. Hence, we assume that there are factors influencing technology transfer and which might result in some kind of guidelines.

4.4 | Inferences and implications for future work

The presented literature review of technology transfer in software engineering revealed a variety of different solution proposal to foster technology transfer as well as success factors and barriers for technology transfer in software engineering. The results of the study indicate that technology transfer is of importance to all areas of software engineering as well as for various industry domains and not subject to particular areas and domains.

It must be recognized that there exists a multitude of technology transfer approaches and particularly reported experiences on technology transfer that have only been reluctantly used. The lack of secondary studies, in particular, recent studies, making use of the huge data set provided by the experience reports is thus surprising. However, surveys, case studies, and experience reports showed potential for improving technology transfer practices. For example, in Jedlitschka et al,[68] guidelines for reporting information relevant for technology transfer have been proposed. As these guidelines, eg, were included into Jedlitschka et al,[78] which provides more holistical guidelines for reporting experimental research and has been widely acknowledged, it is to be analyzed whether recent technology transfer reports have made use of these. Hence, future work should investigate whether the impact of technology transfer has changed over the last decades.

Beside such questions related to further knowledge gain, it turned out that there is a lack of solution proposals and evaluation research dealing with combinations of different solution approaches. All proposed solutions suggest just one approach, eg, either an educational approach or a collaboration approach, but no combination of both. In contrast, since different solution approaches address different success factors, it seems beneficial to combine different solution approaches, such as collaboration, education, and mediums, for example, to make full use of their complementing benefits. However, as there exist no works on this so far, future work should deal with this research direction.

5 | CONCLUSION

Software engineering research often aims at solving real-world problems of industry. However, approaches developed by academia spread slowly across industry. Approaches for technology transfer aim at closing this gap between academic research and application in industrial practice. Of particular interest are also reports of successful or unsuccessful technology transfer, as these provide the opportunity for other researches to learn and adapt their approaches to technology transfer. However, only few reports and approaches and even less secondary studies have been published over the last decades.

This paper contributed an analysis of the state of the art in technology transfer in software engineering. Therefore, the approaches proposed were identified and classified to provide an overview over existing techniques that might be applicable. Furthermore, we analyzed the success factors and barriers for technology transfer in software engineering, which have been reported.

This paper has shown that success factors reported in the literature are technology related, process related, or organization related. Most important for the technology to be transferred seems to be that the technology has undergone thorough evaluation and is adaptable and that practitioners have already been involved during development of the technology to ensure that the technology developed adequately addresses industry needs. Regarding the transfer process, it is important that a good information flow is established and the researches are present during the introduction of the technology. Furthermore, transferees must receive sufficient training, appropriate mediums must be used, and a cost-benefit analysis must be conducted to show the concrete benefit in the company. Regarding the organization, it is of vital importance that the receiving company ensures that someone is in charge for introducing the technology and additionally serves as champion or advocate of the technology to be transferred.

This paper has also shown the most important barriers to successful technology transfer that have been reported in literature. The major hindrance for technology transfer is a mismatch in the perceptions of academia and industry. Academia and industry typically have different cultures and different expectations, needs, and goals and use different vocabulary. If partaking personnel (ie, the researchers and practitioners involved in the transfer process) are not aware of these mismatches, do not recognize the mismatches, and do not act to reach understanding and trust between industry and academic partners, the technology transfer project seems very likely to be condemned. Beside these mismatches, a further vital barrier is the immaturity of the technology to be transferred.

These findings allow researchers to define technology transfer processes that make use of the success factors and avoid the barriers. As this paper has also shown, there is a need for technology transfer approaches combining proposed technology transfer approaches to create a more thorough idea of technology transfer. To do so, considering the barriers and success factors is of vital importance and will help create better approaches to technology transfer.

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REFERENCES

1. Wieringa R. Design science methodology: principles and practice. In: Proceedings of the 32nd ACM/IEEE International Conference on Software Engineering - Volume 2. pp. 493–494. ACM, New York, NY, USA; 2010.
2. Basili VR. The experimental paradigm in software engineering. In: Rombach HD, Basili VR, Selby RW, eds. *Experimental Software Engineering Issues: Critical Assessment and Future Directions*. Berlin Heidelberg: Springer; 1993:1-12.
3. Salman I, Misirli AT, Juristo N. Are students representatives of professionals in software engineering experiments? In: 2015 IEEE/ACM 37th IEEE International Conference on Software Engineering (ICSE). pp. 666–676; 2015.
4. Redwine ST Jr, Riddle WE. Software technology maturation. In: Proceedings of the 8th International Conference on Software Engineering. pp. 189–200. IEEE Computer Society Press, Los Alamitos, CA, USA; 1985.
5. Selic B. The iceberg effect: on technology transfer from research to practice. In: 2015 IEEE/ACM 2nd International Workshop on Software Engineering Research and Industrial Practice (SER IP). pp. 58–61; 2015.
6. Pfleeger SL. Understanding and improving technology transfer in software engineering. *J Syst Softw*. 1999;47(2-3):111-124.
7. Teece DJ. Technology transfer by multinational firms: the resource cost of transferring technological know-how. *Econ J*. 1977;87:242-261.
8. Boehm B. A view of 20th and 21st century software engineering. In: Proceedings of the 28th International Conference on Software Engineering. pp. 12–29. ACM, New York, NY, USA; 2006.
9. Finkelstein A, Kramer J. Software engineering: a roadmap. In: Proceedings of the Conference on the Future of Software Engineering. pp. 3–22. ACM, New York, NY, USA; 2000.
10. Ivarsson M, Gorschek T. Technology transfer decision support in requirements engineering research: a systematic review of REj. *Requir Eng*. 2009;14(3):155-175.
11. Geisler E. Technology transfer: toward mapping the field, a review, and research directions. *J Technol Transf*. 1993;18(3-4):88-93.
12. Rombach D, Achatz RE. Research collaborations between academia and industry. In: Future of Software Engineering, 2007. FOSE'07. pp. 29–36; 2007.
13. Fowler P, Levine L. From theory to practice: technology transition at the SEI. In: Proceedings of the Twenty-Seventh Hawaii International Conference on System Sciences, 1994. pp. 483–497; 1994.
14. Shull F, Carver J, Travassos GH. An empirical methodology for introducing software processes. Presented at the Proceedings of the ACM SIGSOFT Symposium on the Foundations of Software Engineering; 2001.
15. Curran LJ. "A" for effort (technology transfer education). *IEEE Spectr*. 1993;30(2):50-52.
16. Hallinan S, Paul G. A graduate's role in technology transfer: from requirements to design with UML. In: Proceedings of the IASTED International Conference on Software Engineering: Part of the 23rd IASTED International Multi-Conference on Applied Informatics, SE 2005. pp. 94–99; 2005.
17. Chookittikul W, Kourik JL, Maher PE. Reducing the gap between academia and industry: the case for agile methods in Thailand. In: 2011 Eighth International Conference on Information Technology: New Generations (ITNG). pp. 239–244; 2011.
18. Michalik B, Nawrocki J, Ochodek M. 3-step knowledge transition. In: ACM/IEEE 30th International Conference on Software Engineering, 2008. ICSE'08. pp. 741–748; 2008.
19. Junker M, Broy M, Hauptmann B, Bohm W, Femmer H, Eder S, Juergens E, Janssen R, Vaas R. Principles and a process for successful industry cooperation—the case of TUM and Munich Re. In: 2015 IEEE/ACM 2nd International Workshop on Software Engineering Research and Industrial Practice (SER&IP). pp. 50–53; 2015.
20. Fraser S, Mancl D. Strategies for building successful company-university research collaborations. In: Proceedings of the 3rd International Workshop on Software Engineering Research and Industrial Practice. pp. 10–15. ACM, New York, NY, USA; 2016.
21. Hinchey MG, Pressburger T, Markosian L, Feather MS. The NASA software research infusion initiative: successful technology transfer for software assurance. In: Proceedings of the 2006 International Workshop on Software Technology Transfer in Software Engineering. pp. 43–48. ACM, New York, NY, USA; 2006.
22. Zelkowitz MV. Software engineering technology infusion within NASA. *IEEE Trans Eng Manag*. 1996;43(3):250-261.
23. Lindvall M, Stratton WC, Sibol DE, et al. Connecting research and practice: an experience report on research infusion with software architecture visualization and evaluation. *Innov Syst Softw Eng*. 2010;8:255-277.
24. Kitchenham BA, Budgen D, Brereton P. *Evidence-Based Software Engineering and Systematic Reviews*. Boca Raton, FL, USA: Chapman & Hall; 2016.
25. Petersen K, Vakkalanka S, Kuzniarz L. Guidelines for conducting systematic mapping studies in software engineering: an update. *Inf Softw Technol*. 2015;64:1-18.
26. Kitchenham B, Brereton P. A systematic review of systematic review process research in software engineering. *Inf Softw Technol*. 2013;55(12):2049-2075.
27. Zhang H, Babar MA, Tell P. Identifying relevant studies in software engineering. *Inf Softw Technol*. 2011;53(6):625-637.
28. Rodríguez P, Kuvaja P, Oivo M. Lessons learned on applying design science for bridging the collaboration gap between industry and academia in empirical software engineering. In: Proceedings of the 2nd International Workshop on Conducting Empirical Studies in Industry. pp. 9–14. ACM, New York, NY, USA; 2014.
29. Sharp H, Plonka L, Taylor K, Gregory P. Overcoming challenges in collaboration between research and practice: the agile research network. In: Proceedings of the 1st International Workshop on Software Engineering Research and Industrial Practices. pp. 10–13. ACM, New York, NY, USA; 2014.
30. Diebold P, Vetro A, Mendez Fernandez D. An exploratory study on technology transfer in software engineering. In: 2015 ACM/IEEE International Symposium on Empirical Software Engineering and Measurement (ESEM). pp. 1–10; 2015.
31. Diebold P, Vetrò A. Bridging the gap: SE technology transfer into practice: study design and preliminary results. In: Proceedings of the 8th ACM/IEEE International Symposium on Empirical Software Engineering and Measurement. pp. 52:1–52:4. ACM, New York, NY, USA; 2014.
32. Duarte CHC. Patterns of cooperative technology development and transfer for software-engineering-in-the-large. In: 2015 IEEE/ACM 2nd International Workshop on Software Engineering Research and Industrial Practice (SER&IP). pp. 32–38; 2015.

33. Grigoleit F, Vetro A, Mendez Fernandez D, Bohm W, Diebold P. In quest for proper mediums for technology transfer in software engineering. In: 2015 ACM/IEEE International Symposium on Empirical Software Engineering and Measurement (ESEM). pp. 1–4; 2015.
34. Laird L, Yang Y. Transferring software engineering research into industry: the Stevens way. In: 2015 IEEE/ACM 2nd International Workshop on Software Engineering Research and Industrial Practice (SER&IP). pp. 46–49; 2015.
35. Yamashita A. Integration of SE research and industry: reflections, theories and illustrative example. In: 2015 IEEE/ACM 2nd International Workshop on Software Engineering Research and Industrial Practice (SER&IP). pp. 11–17; 2015.
36. Cruzes DS, Dyba T. Synthesizing evidence in software engineering research. In: Proceedings of the 2010 ACM-IEEE International Symposium on Empirical Software Engineering and Measurement. p. 1. ACM; 2010.
37. Wieringa R, Maiden N, Mead N, Rolland C. Requirements engineering paper classification and evaluation criteria: a proposal and a discussion. *Requir Eng*. 2005;11:102-107.
38. Engström E, Runeson P. Software product line testing—a systematic mapping study. *Inf Softw Technol*. 2011;53(1):2-13.
39. Paternoster N, Giardino C, Unterkalmsteiner M, Gorschek T, Abrahamsson P. Software development in startup companies: a systematic mapping study. *Inf Softw Technol*. 2014;56(10):1200-1218.
40. Rombach D. Fraunhofer: the German model for applied research and technology transfer. In: Proceedings of the 2000 International Conference on Software Engineering, 2000. pp. 531–537; 2000.
41. Freedman P, Quesnel L, Roy D. Crim: a new model for technology development and technology transfer. In: Canadian Conference on Electrical and Computer Engineering, 1993. pp. 179–183 vol.1; 1993.
42. Harrison W. Technology transfer and the tech broker. *IEEE Softw*. 2006;23:5-7.
43. Baldassarre MT, Bruno G, Caivano D, Visaggio G. The role of empirical evidence for transferring a new technology to industry. In: Bomarius F, Oivo M, Jaring P, Abrahamsson P, eds. *Product-Focused Software Process Improvement*. Berlin Heidelberg: Springer; 2009:111-125.
44. Baldassarre MT, Caivano D, Visaggio G. Empirical studies for innovation dissemination: ten years of experience. In: Proceedings of the 17th International Conference on Evaluation and Assessment in Software Engineering. pp. 144–152. ACM, New York, NY, USA; 2013.
45. Kalinowski M, Travassos GH. ISPIS: from conception towards industry readiness. In: XXVI International Conference of the Chilean Society of Computer Science, 2007. SCCC'07. pp. 132–141; 2007.
46. Butler RW, Caldwell JL, Carreno VA, Holloway CM, Miner PS, Di Vito BL. NASA Langley's research and technology-transfer program in formal methods. In: Proceedings of the Tenth Annual Conference on Computer Assurance, 1995. COMPASS'95. Systems Integrity, Software Safety and Process Security. pp. 135–149; 1995.
47. Abercrombie DA. A case study of cooperative university/government/industry education and research. In: Proceedings of the Tenth Biennial University/Government/Industry Microelectronics Symposium pp. 41–45; 1993.
48. Lahdeniemi M, Jaakkola H. Application of technology transfer to SME. In: Engineering Management Conference, 1994. "Management in Transition: Engineering a Changing World", Proceedings of the 1994 IEEE International. pp. 119–122; 1994.
49. Skevoulis S. Engineering a successful partnership between academia and the financial industry: a software engineering program for IT professionals. In: 2011 24th IEEE-CS Conference on Software Engineering Education and Training (CSEE&T). pp. 343–350; 2011.
50. Werner CML, Travassos GH, da Rocha ARC. An OO software engineering training experience within a collaboration project between academia and industry. In: Technology of Object-Oriented Languages, 1998. TOOLS 27. Proceedings. pp. 290–294; 1998.
51. Redford M, Price E. The Teaching Company scheme, an academic-industry partnership—a case study. In: Proceedings of the Tenth Biennial University/Government/Industry Microelectronics Symposium. pp. 29–36; 1993.
52. Abernethy K, Kelly J, Sobel A, Kiper JD, Powell J. Technology transfer issues for formal methods of software specification. In: 13th Conference on Software Engineering Education amp; Training, 2000. Proceedings. pp. 23–31; 2000.
53. Pani FE, Sanna D, Marchesi M, Concas G. Transferring FAME, a methodology for assessing open source solutions, from university to SMEs. In: D'Atri A, Marco MD, Braccini AM, Cabiddu F, eds. *Management of the Interconnected World*. Physica-Verlag HD; 2010:495-502.
54. Iyer SV, Singh T, Terstriep J, Ravaioli U. World wide web based technology transfer testbed. In: Proceedings of the Eleventh Biennial University/Government/Industry Microelectronics Symposium pp. 16–20; 1995.
55. Schuh G, Aghassi S. Technology transfer portals: a design model for supporting technology transfer via social software solutions. In: 2013 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM). pp. 43–47; 2013.
56. Schuh G, Aghassi S, Valdez AC. Supporting technology transfer via web-based platforms. In: Technology Management in the IT-Driven Services (PICMET), 2013 Proceedings of PICMET'13: pp. 858–866 2013.
57. Schuh G, Aghassi S, Schneider B Bartels P. Influencing factors and requirements for designing customized technology transfer portals. In: 2014 IEEE International Conference on Management of Innovation and Technology (ICMIT). pp. 105–110; 2014.
58. Schuh G, Kabasci P, Aghassi S, Drescher T. The knowledge exchange: a platform for pooling technology intelligence knowledge between practitioners, researchers, and technologists. In: 2014 IEEE International Conference on Management of Innovation and Technology (ICMIT). pp. 99–104; 2014.
59. Heuer A, Diebold P, Bandyszak T. Supporting technology transfer by providing recommendations for writing structured guidelines. In: Vierter Workshop zur Zukunft der Entwicklung softwareintensiver, eingebetteter Systeme. pp. 47–56; 2014.
60. Berniker E. Models of technology transfer. (A dialectical case study). In: Technology Management: The New International Language pp. 499–502; 1991.
61. Buxton JN, Malcolm R. Software technology transfer. *Softw Eng J*. 1991;6(1):17-23.
62. Punter T, Krikhaar RL, Bril RJ. Sustainable technology transfer. In: Proceedings of the 2006 International Workshop on Software Technology Transfer in Software Engineering. pp. 15–18. ACM, New York, NY, USA; 2006.
63. Gorschek T, Wohlin C, Carre P, Larsson S. A model for technology transfer in practice. *IEEE Softw*. 2006;23(6):88-95.
64. Cantu-Ortiz FJ. A strategy for transferring expert systems technology to industry. In: IEEE Conference on Managing Expert System Programs and Projects, 1990. Proceedings. pp. 70–75; 1990.

65. Cecchet E. From research prototypes to industrial strength open source products—the ObjectWeb experience. In: Vojtáš P, Bieliková M, Charron-Bost B, Sýkora O, eds. *SOFSEM 2005: Theory and Practice of Computer Science*. Berlin Heidelberg: Springer; 2005:17-27.

66. Curtis B. From MCC to CMM: technology transfers bright and dim. In: Proceedings of the 2000 International Conference on Software Engineering, 2000. pp. 521–530 (2000).

67. Andrade J, Ares J, Rodríguez S, López FJ, Pazos J, Silva A. Computer-assisted discrepancy management—a case study in research transfer to industry. *J Res Pract Inf Technol*. 2004;36:295-315.

68. Jedlitschka A, Ciolkowski M, Denger C, Freimut B, Schlichting A. Relevant information sources for successful technology transfer: a survey using inspections as an example. In: First International Symposium on Empirical Software Engineering and Measurement, 2007. ESEM 2007. pp. 31–40; 2007.

69. Fraser S. Reflections on software engineering research collaborations: from Ottawa to the software engineering institute to Silicon valley. In: 2015 IEEE/ACM 2nd International Workshop on Software Engineering Research and Industrial Practice (SER&IP). pp. 5–10; 2015.

70. Amsden DC, Amsden AA. The KIVA story: a paradigm of technology transfer. *IEEE Trans Prof Commun*. 1993;36(4):190-195.

71. Huang L, Port D. Relevance and alignment of real-client real-project courses via technology transfer. In: 2011 24th IEEE-CS Conference on Software Engineering Education and Training (CSEE T). pp. 189–198; 2011.

72. Aschauer T, Dauenhauer G, Pree W. A modeling language's evolution driven by tight interaction between academia and industry. In: Proceedings of the 32nd ACM/IEEE International Conference on Software Engineering - Volume 2. pp. 49–58. ACM, New York, NY, USA; 2010.

73. Smith J, Wright P, McDermid J, Cockram T. Technology transfer gap: a case study of academic-industrial technology transfer. In: Conference on Academic and Industrial Cooperation in Space Research. pp. 63–72; 1998.

74. Mubeen S, Lawson H, Lundbäck J, Gålnander M, Lundbäck KL. Provisioning of predictable embedded software in the vehicle industry: the Rubus approach. In: 2017 IEEE/ACM 4th International Workshop on Software Engineering Research and Industrial Practice (SER&IP). pp. 3–9; 2017.

75. Gibson DV, Harlan GT. Inter-organizational technology transfer: the case of the NSF science and technology centers. In: Proceedings of the Twenty-Eighth Hawaii International Conference on System Sciences, 1995. pp. 661–670 vol.4; 1995.

76. Bass M. A survey of software related academic collaborations at Siemens. In: Proceedings of the 2006 International Workshop on Software Technology Transfer in Software Engineering. pp. 55–58. ACM, New York, NY, USA; 2006.

77. Zelkowitz MV, Wallace DR, Binkley DW. Culture conflicts in software engineering technology transfer. In: NASA Goddard Software Engineering Workshop; 1998.

78. Jedlitschka A, Ciolkowski M, Pfahl D. Reporting experiments in software engineering. In: Shull F, Singer J, Sjøberg DIK, eds. *Guide to Advanced Empirical Software Engineering*. London: Springer; 2008:201-228.

79. Cañete-Valdeón JM. How influential has academic and industrial research been in current software life cycles? A retrospective analysis of four mainstream activities. *Inf Softw Technol*. 2013;55(2):226-240.

80. Cartaxo B, Pinto G, Vieira E, Soares S. Evidence briefings: towards a medium to transfer knowledge from systematic reviews to practitioners. In: Proceedings of the 10th ACM/IEEE International Symposium on Empirical Software Engineering and Measurement. pp. 57:1–57:10. ACM, New York, NY, USA; 2016.

81. Colyer AM. From research to reward: challenges in technology transfer. In: Proceedings of the 2000 International Conference on Software Engineering, 2000. pp. 569–576; 2000.

82. Rezabal MI, Etxeberria Elorza L, Elkorobarrutia Letona X. Reuse in safety critical systems: educational use case. In: 2013 39th EUROMICRO Conference on Software Engineering and Advanced Applications (SEAA). pp. 402–407; 2013.

83. Jøergensen M. Working with industry: stories of successful and failed research-industry collaborations on empirical software engineering. In: 2017 IEEE/ACM 5th International Workshop on Conducting Empirical Studies in Industry (CESI). pp. 46–52; 2017.

84. Jorge LA, Quaresma E, Mira F, Fonseca A, Rosa P, Barruncho LMF, Ferreira LAFM, Carvalho PMS, Grave SNC. DPlan: a case study on the cooperation between university and industry. In: Power Tech Proceedings, 2001 IEEE Porto. pp. 6 pp. vol.1-; 2001.

85. Knodel J, Muthig D, Haury U, Meier G. Architecture compliance checking—experiences from successful technology transfer to industry. In: 12th European Conference on Software Maintenance and Reengineering, 2008. CSMR 2008. pp. 43–52; 2008.

86. Punter T, Krikhaar RL, Bril RJ. Software engineering technology innovation—turning research results into industrial success. *J Syst Softw*. 2009;82(6):993-1003.

87. Tillmann N, de Halleux J, Xie T. Transferring an automated test generation tool to practice: from Pex to fakes and code digger. In: Proceedings of the 29th ACM/IEEE International Conference on Automated Software Engineering. pp. 385–396. ACM, New York, NY, USA; 2014.

88. van Lamsweerde A. Goal-oriented requirements engineering: a roundtrip from research to practice [engineering read engineering]. In: 12th IEEE International Requirements Engineering Conference, 2004. Proceedings. pp. 4–7; 2004.

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APPENDIX A

Paper	Research method	Proposed solution	Success factor	Barrier	Technology	Recipient
Redwine and Riddle[4]	Proposal of a solution	Model/theory	Evaluation, adaptability, training, champion/advocate/broker, commitment	Immaturity, risk aversion, "not-invented-here" syndrome		
Selic[5]	Opinion paper		Adaptability, adherence to standards	Mismatch in expectations/needs/goals	Product	No particular
Ivarsson and Gorschek[10]	Experience paper		Evaluation	No or insufficient evaluation	No particular	No particular
Rombach and Achatz[12]	Opinion paper			Unrecognized needs/missed potential, "not-invented-here" syndrome, mismatch in cultures	Process	Health, finance, space and aerospace, electronics
Fowler and Levine[13]	Evaluation research	Institution	Champion/advocate/broker	Mismatch in vocabularies	Process	No particular
Curran[15]	Proposal of a solution	Student education	Champion/advocate/broker	Immaturity, mismatch in expectations/needs/goals		
Hallinan and Paul[16]	Proposal of a solution	Student education	Adherence to standards	Lack of experience		
Chookittikul et al[17]	Evaluation research	Student education	Training		Process	No particular
Michalik et al[18]	Evaluation research	Student education	Training, openness to change	"Not-invented-here" syndrome, anti-innovation attitude	Process	Software development
Junker et al[19]	Experience paper		Practitioners involved in development, addresses industry needs, information flow		Process	Finance
Fraser and Mancl[20]	Experience paper		Evaluation		No particular	Telecommunications
Hinchey et al[21]	Experience paper		Evaluation, appropriate mediums	Immaturity, management overhead	Process	Space and aerospace
Zelkowitz[22]	Experience paper		Evaluation, adaptability, researchers present	Risk aversion	Process	Space and aerospace
Lindvall et al[23]	Experience paper		Evaluation, adaptability, researchers present, champion/advocate/broker, process integration	Immaturity, missing documentation, mismatch in expectations/needs/goals	Product	Space and aerospace
Rodríguez et al[28]	Evaluation research	Empirical	Practitioners involved		Process	Electronics

(Continued)

Paper	Research method	Proposed solution	Success factor	Barrier	Technology	Recipient
			in development, training, researchers present, champion/advocate/broker			
Sharp et al[29]	Proposal of a solution	Institution	Practitioners involved in development	Mismatch in information sources deemed important		
Diebold et al[30]	Experience paper		Addresses industry needs, information flow, researchers present	Immaturity, mismatch in culture	No particular	Other embedded
Diebold and Vetrò[31]	Experience paper		Appropriate mediums		No particular	Other embedded
Duarte[32]	Opinion paper			Immaturity, no or insufficient evaluation, lack of experience	Product	Finance, automotive, space and aerospace, electronics, software development
Grigoleit et al[33]	Evaluation research	Other medium	Appropriate mediums	Immaturity, unrecognized needs/missed potential, unawareness	Process	Other embedded
Laird and Yang[34]	Evaluation research	Institution	Information flow, champion/advocate/broker		Process	No particular
Yamashita[35]	Opinion paper		Tool support, adherence to standards, cost-benefit/risk analysis, practitioners involved in development	Mismatch in cultures, mismatch in vocabularies	Process	No particular
Rombach[40]	Evaluation research	Institution	Addresses industry needs, long-term collaboration		Process	Finance, automotive, software development
Freedman et al[41]	Proposal of a solution	Institution	Practitioners involved in development	Mismatch in culture, mismatch in expectations/needs/goals		
Harrison[42]	Evaluation research	Institution	Champion/advocate/broker	Mismatch in cultures	No particular	No particular
Baldassarre et al[43]	Evaluation research	Empirical	Evaluation, commitment	Immaturity	Process	No particular
Baldassarre et al[44]	Evaluation research	Empirical	Evaluation, information flow, cost-benefit/risk analysis		No particular	No particular
Kalinowski and Travassos[45]	Proposal of a solution	Empirical	Evaluation, adaptability			
Butler et al[46]	Evaluation research	Project	Practitioners involved		Process	Space and aerospace

(Continued)

Paper	Research method	Proposed solution	Success factor	Barrier	Technology	Recipient
			in development, adaptability, champion/ advocate/ broker			
Abercrombie[47]	Evaluation research	Student education	Information flow, champion/ advocate/ broker	Lack of involvement	No particular	Electronics
Lahdeniemi and Jaakkola[48]	Evaluation research	Professional education	Addresses industry needs		No particular	No particular
Skevoulis[49]	Evaluation research	Professional education	Practitioners involved in development, adaptability, training, long-term collaboration	Mismatch in cultures	Process	Finance
Werner et al[50]	Evaluation research	Professional education	Training		Process	Telecommunications
Redford and Price[51]	Evaluation research	Professional education	Practitioners involved in development		Product	Electronics
Abernethy et al[52]	Evaluation research	Professional education	Training, appropriate mediums		Process	Space and aerospace
Pani et al[53]	Evaluation research	Development tool	Evaluation, adaptability	Mismatch in expectations/ needs/goals	Process	No particular
Iyer et al[54]	Proposal of a solution	Web-based tool	Practitioners involved in development			
Schuh and Aghassi[55]	Proposal of a solution	Web-based tool				
Schuh et al[56]	Proposal of a solution	Web-based tool				
Schuh et al[57]	Proposal of a solution	Web-based tool				
Schuh et al[58]	Proposal of a solution	Web-based tool				
Heuer et al[59]	Proposal of a solution	Other medium				
Berniker[60]	Evaluation research	Model/ theory			No particular	Space and aerospace
Buxton and Malcolm[61]	Proposal of a solution	Model/ theory	Tool support, cost-benefit/ risk analysis, commitment	Unawareness, mismatch in cultures		
Punter et al[62]	Proposal of a solution	Model/ theory	Evaluation, champion/ advocate/ broker	No or insufficient evaluation		
Gorschek et al[63]	Evaluation research	Model/ theory	Practitioners involved in development, adaptability, researchers present, piloting, introduction to large parts/entire company, commitment, trust	No or insufficient evaluation, lack of objectiveness, mismatch in vocabularies	Process	Industry automation

(Continued)

Paper	Research method	Proposed solution	Success factor	Barrier	Technology	Recipient
Cantu-Ortiz[64]	Proposal of a solution	Other solution	Addresses industry needs, cost-benefit/ risk analysis, champion/ advocate/ broker, commitment			
Cecchet[65]	Proposal of a solution	Other solution	Practitioners involved in development, long-term viability	Immaturity, no or insufficient evaluation		
Curtis[66]	Opinion paper		Adaptability, cost-benefit/ risk analysis		Process	Space and aerospace, electronics, software development
Andrade et al[67]	Experience paper		Information flow, no strict deadlines	Lack of adaptability of existing infrastructure, lack of objectiveness, mismatch in cultures, mismatch in vocabulary	Product	Industry automation
Jedlitschka et al[68]	Experience paper		Information flow, cost-benefit/ risk analysis, appropriate mediums		Process	No particular
Fraser[69]	Opinion paper		Practitioners involved in development, researchers present		Product	Telecommunications
Amsden and Amsden[70]	Experience paper		Practitioners involved in development, information flow, champion/ advocate/ broker	Immaturity	Product	Automotive
Huang and Port[71]	Evaluation research	Student education	Evaluation, addresses industry needs	Immaturity	Product	Software development
Aschauer et al[72]	Experience paper		Adaptability, tool support		Product, process	Health, finance
Smith et al[73]	Evaluation research	Institution		Aversion to extensive training effort, mismatch in cultures, mismatch in vocabularies	Process	Space and aerospace
Mubeen et al[74]	Experience paper		Training, tool support	No or insufficient evaluation	Process	Automotive
Gibson and Harlan[75]	Evaluation research	Institution	Practitioners involved in development, researchers present, appropriate mediums	Mismatch in culture	No particular	No particular

(Continued)

Paper	Research method	Proposed solution	Success factor	Barrier	Technology	Recipient
Bass[76]	Experience paper		Cost-benefit/risk analysis, champion/advocate/broker	Lack of adaptability of existing infrastructure, aversion to extensive training effort, mismatch in cultures	Product, process	No particular
Zelkowitz et al[77]	Experience paper			No or insufficient evaluation, mismatch in culture	No particular	No particular
Cañete-Valdeón[79]	Experience paper		Evaluation		Process	No particular
Cartaxo et al[80]	Proposal of a solution	Other medium	Evaluation	Mismatch in information sources deemed important		
Colyer[81]	Evaluation research	Institution	Clear roadmap, risk management	Mismatch in expectations/needs/goals	No particular	No particular
Rezabal et al[82]	Experience paper				Process	Other embedded
Jøergensen[83]	Opinion paper		Practitioners involved in development, evaluation	Mismatch in cultures	No particular	No particular
Jorge et al[84]	Experience paper		Practitioners involved in development, addresses industry needs		No particular	Telecommunications
Knodel et al[85]	Experience paper		Adaptability	No or insufficient evaluation	Process	Electronics
Punter et al[86]	Evaluation research	Model/theory			Process	Electronics
Tillmann et al[87]	Experience paper		Practitioners involved in development, evaluation, tool support, trust	"Not-invented-here" syndrome mismatch in cultures	Product	Software development
van Lamsweerde[88]	Opinion paper		Piloting	Risk aversion	Process	Telecommunications, health, automotive, space and aerospace, industry automation