An Exploratory Study on Technology Transfer in Software Engineering

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Abstract—*Background*: **Technology transfer is one key to the success of research projects, especially in Software Engineering, where the (practical) impact of the outcome may depend not only on the reliability and feasibility of technologies, but also on their applicability to industrial settings. However, there is limited knowledge on the current state of practice and how to assess the success of technology transfer.**

Objective: **We aim at elaborating a set of hypotheses on how technology transfer takes place in Software Engineering research projects.**

Method: **We designed an exploratory survey with the participants of two large research projects in Germany, which involve both industrial and academic partners in the area of model-driven development for embedded systems.**

Results: **Base on the extracted respondents answers of this survey, we defined a resulting theory which is based on the following set of main hypothesis: Most of the technologies developed in research projects are not mature enough for a direct application, but need post-project customisation to fit the industrial contexts (H_1). Common models that represent technology transfer as a transaction of an object from a transferor to a transferee does not fit industrial reality (H_2). Additionally, technology transfer takes place without an explicit process (H_3). Regarding transfer mediums, most used mediums are human-intensive (H_5) and industry organisations gain new knowledge mainly within their own confines (H_4). Finally the motivations that drive the transfer in industry and academia are heterogenous (H_6).**

Conclusions: **From the theoretical perspective, this theory and set of hypotheses extracted from the survey results will be further explored and tested in different follow-up activities. This initial set, however, already may serve as a basis for independent assessments from other researchers to collaboratively shed light on a how technology transfer takes place in Software Engineering research projects, which are the barriers, and how to improve the transfer into practice. From the practical perspective, our results may be used as a basis for an evaluation framework for the transfer of the developed technologies in our projects. This would also help companies in getting new developed technologies transfer easier to their specific context.**

Index Terms—**Technology Transfer, Transfer into Practice, Empirical Software Engineering, Survey Research.**

I. INTRODUCTION

The success of research projects in Software Engineering (SE) often depends on two aspects: (1) producing technically sound solutions that address their intended purpose, i.e. achieve the project goals, and (2) transferring the results to the community to foster innovation. The second part, Technology Transfer (TT), might be as difficult as the first one due to the challenges involved in adapting technological solutions to specific organisational contexts, or even more, reshaping an existing organisation to embrace a ground-breaking innovation [19]. Assessing the transfer entails also numerous difficulties. In fact, traditional metrics used for this purpose, such as number of patents or publications [6], do not capture the effectiveness of technology transfer. Issuing a patent or a publication might indicate that the solutions developed in a project are technically sound, but it say little about the success of the transfer of project results to industrial practice (e.g., as reported in [17]).

To better understand the current state of practice of TT in SE research projects, we designed an exploratory study which should also reveal barriers for a successful transfer and how to improve it[1]. Exemplary aspects we investigated are how academic and industrial partners differ in their motivations [5], through which type of dissemination the technologies are transferred, which TT processes they follow in their respecting research settings. We conduct our study in the context of two large, heterogeneous research projects taking place in Germany (ARAMiS[2] and SPES_XT[3]), each involving more than 20 partners from both academia and industry in the context of model-driven development in embedded systems. For the study, we applied an exploratory study realised via survey research. The overall design of the survey and a few preliminary results can be taken from our previously published material in [10]. In the paper at hands, we now provide more details on the design by focussing on the specific survey questions, we report on the complete set of answers collected, and we induce a set of research hypotheses to steer future empirical evaluations.

The remainder of the paper is as follows: In Sect. II, we introduce the study design. In Sect. III, we report on the survey results, aggregated and segmented by both organisation type and size. We induce a set of hypotheses in Sect. IV, highlighting what is already supported by literature and what differs. Finally, we analyse the limitations of the design and of the findings in Sect. V, before summarise our contribution in Sect. VI.

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[1]Projects (partially) funded by the government, working in applied research fields (e.g. automotive, avionics, railway, automation)

[2] http://www.projekt-aramis.de/

[3] http://spes2020.informatik.tu-muenchen.de/

II. STUDY DESIGN

A. Goals

Technology Transfer (TT) is formally defined as "*the process of sharing knowledge, machines, equipment, methods, tools, techniques, processes, and facilities with the aim of facilitating accessibility of scientific and technological developments from primary discoverers or transferors to potential users or transferees/recipients, who will exploit the technology into new products, processes, applications, and business models*" [4] [25].

According to this definition, the TT process can be specified as the transaction of a transfer object (such as knowledge or machinery [25]) between the transferor (an organisation seeking the transfer of an object) and the transferee (an organisation adopting the transfer object) over a medium (e.g., guidelines). This specification was incorporated in the survey with the intention of establishing a common understanding of TT for all participants (see also the diagram in the center of Fig. 2). in context of the survey, we decided to simplify two things: (1) TT is a unidirectional activity from the transferor to the transferee, and (2) is not mediated by further actors between the transferor and the transferee. We are aware that this model does not capture all the complex interactions involved in transferring technology (see for instance [1]); however, the survey context allowed us to safely approximate the transfer with such a concept.

We provided the overall goals of the survey and basic information on the design in a previous publication [10], whereas our study goals (SG) are briefly summarised in Tab. I using the Goal template from GQM[3]:

TABLE I: Study goals.

Characterize	the TT of SE objects
With respect to	(SG 1) to the current state of practice ,
	(SG 2) the transfer mediums used, and
	(SG 3) improvements / future transfer trends
From the perspective of	industry and academia
In context of	the projects ARAMIS and SPES_XT.

B. Survey Instrument

As instrument, we used a questionnaire divided into five interrelated sections represented in Fig. 1. The codes contained in Fig. 1 are the question identifiers, which are listed in Table II and in Table III. The left side of the figure shows sections for distilling the demographics. This part was defined for the segmentation of the results and to navigate though the questionnaire via conditional questions. The main segmentation of the data is the differentiation of industry and academia as well as the different organisational size (large vs. small companies). The right part of the figure contains the sections linked to our study goals: (SG1) the current state of TT, (SG2) assessment medium, and (SG3) improvements which will be detailed in the following paragraphs.

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[4]We added "tools and techniques" to better fit the SE context
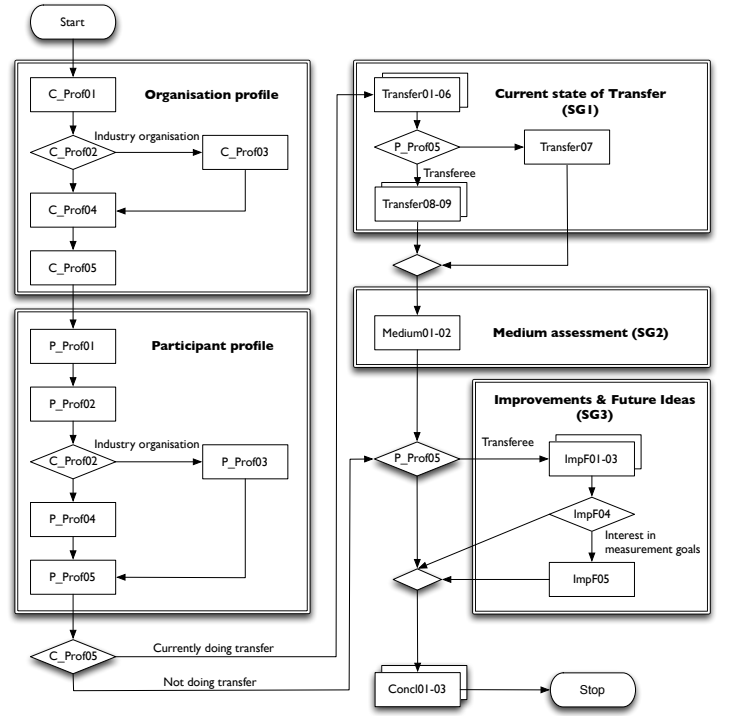

Fig. 1: Questionnaire structure

We mainly tailored the validated demographic questions of [9]. Similar as done by Rombach and Reinhold [22], we specified only the organisation type to allow for fine-grained distinctions, e.g. between fundamental and applied research as well as between organisations, research units, and their business units. In addition, we asked for the academic degree as well as for previous work in industry or academia (academia includes universities and research institutes). Respondents could access the first two sections (right part of Fig. 1) only if they were currently performing TT (*C Prof05*). Herein, we summarise the aspects investigated for our three goals (SG).

a) SG1 - Current state: We are interested in assessing the current state of five different facets (question codes in parentheses).

1) The motivations for TT (*Transfer01*) using the classification of Reisman [21]: social, economic, operational, strategic, or personal factors.
2) The type of transfer objects (*Transfer02*) from the list provided by the adapted definition in [25].
3) The transfer process description (*Transfer04*) as an open question.
4) The transfer time (*Transfer05 to 08*) including average duration, frequency, and the related perception to compare it with [20] (setting a TT duration baseline of 18 years).
5) The trigger of ideas for TT (*Transfer09*).

b) SG2 - Medium assessment: We created a broad classification of mediums and asked the participants to indicate on a 5-point scale of frequency how often they were using them

TABLE II: Survey questions SG1 and SG2

Goal	ID	Question	Scale
(Demographics)	C_Prof01	How many employees are working in your organisation? Valid answers: < 10; 10-49; 50-249; 250-500; > 500	Interval
	C_Prof02	What is your organisation ? Valid answers: University (e.g., TUM); Basic research institute (e.g. Max-Planck- institute); Applied research institute (e.g., Fraunhofer) ; Development company (research unit) (e.g., e.g. Siemens CT); Development company (business unit) (e.g., Siemens BUs); Consulting company (e.g., Accenture); Start-up company; Other (specify)	Nominal
	C_Prof03	In which domain is your organisation working? Valid answers: Automotiv; Avionics; Automation; Railway; Tool; Other(specify)	Nominal
	C_Prof04	In which current research project are you working? Valid answers (multiple choice): SPES; ARAMIS	Nominal
	C_Prof05	Is your organisation performing technology transfer at the moment?	Boolean
	P_Prof01	Which is/are your role(s) in the organisation? Valid answers (multiple choice): Requirements Engineer; Developer; Product Manager; Quality Engineer; Architect; Process Engineer; Tester; Decision Maker; Researcher; Other (specify)	Nominal
	P_Prof02	What is your highest academic qualification? Valid answers: PhD; Diploma; Master; Bachelor; Other (specify)	Nominal
	P_Prof03	Have you ever worked in industry before?	Boolean
	P_Prof04	Have you ever worked in academia (university, research institute) before?	Boolean
	P_Prof05	On which side of the technology transfer are you involved? Valid answers: Transferor; Transferee; Both	Nominal
SG1	Transfer01	What are your motivations for Technology Transfer in Software Engineering? Valid answers (multiple choice): economic factors (e.g., cost savings); social factors (e.g., job satisfaction); operational factors (e.g., improve material); strategic factors (e.g., and / or process innovation); global factors (e.g., political image); personal factors (e.g., knowledge sharing); Other (specify)	Nominal
	Transfer02	What are transfer objects in your current research projects (e.g. SPES-XT, ARAMIS) that you would like to transfer? Valid answers (multiple choice): Knowledge *(can specify)*; Machines *(can specify)*; Equipment *(can specify)*; Methods *(can specify)*; Techniques *(can specify)*; Processes *(can specify)*; Facilities *(can specify)*; Other *(can specify)*	Nominal
	Transfer03	What are the transfer medium(s) you are using at the moment?	-
	Transfer04	How is the technology transfer process performed at the moment in your organization?	-
	Transfer05	How long do you think a technology transfer transaction takes, on average? (from final object to real usage in industry)	-
	Transfer06	Do you think that this time should be...? Valid answers (multiple choice): shorter (specify how much); it's fine like this; longer (specify how much); I don't know	Ordinal
	Transfer07	How often are new transfer objects transferred from your organization? Valid answers (multiple choice): shorter (specify how much); it's fine like this; longer (specify how much); I don't know	Ordinal
	Transfer08	How often are new transfer objects transferred to your organization? Valid answers (multiple choice): shorter (specify how much); it's fine like this; longer (specify how much); I don't know	Ordinal
	Transfer09	Where do you get the trigger for technology transfer? Valid answers (multiple choice): Own company; Competitors; Consulting companies; Other companies; Research; Other (specify)	Nominal
SG2	Medium01	What are the transfer medium(s) you are using at the moment? Valid answers: Personnel exchange; Publications; Internet resources; Conferences; Workshops and meetings; Guidelines; Consultancy; Software, systems, and tools; Licensing and standards; Co-working; Research cooperation; Educational programs 5p. scale values: 1 Never; 2 Rarely; 3 Sometimes; 4 Often; 5 Always; 6 I don't know	Likert 5p
	Medium02	Which transfer mediums are best for which specific transfer objects in your opinion?	-

TABLE III: Survey questions - SG3

Goal	ID	Question	Scale
SG3	ImpF01	What are your goals for SE technology transfer?	-
	ImpF02	How would you measure the technology transfer effectiveness on that goal(s)?	-
	ImpF03	Would empirical evidence of a transfer object help your decision regarding its usage?	Boolean
	ImpF04	Are you interested in starting a technology transfer project with measurement goals?	Boolean
	ImpF05	You just answered that you might be interested in starting a technology transfer project with measurement goals after ongoing research projects (e.g. SPES-XT or ARAMiS). Could you please tell us with which mediums and which object (pairs)?	-
(Concl.)	Concl01	Are you interested in receiving the anonymized results?	-
	Concl02	Are you interested in conducting a short (20 mins) interview on your experience with a Technology Transfer project?	-
	Concl03	Do you have additional comments?	-

(*Medium01*). Building the list and classification of the mediums was a step-wise approach, which included the following action points:

- Analysing the literature (using comprehensive taxonomies previously published, e.g. [5] and [21]), about what they present on different mediums for TT (not exclusive to the SE domain). This resulted in a list of around 80 transfer mediums.
- This list of mediums was then extended by brainstorming workshops held at TUM and Fraunhofer IESE. Based on this, we extended the list to 105 mediums.
- Clustering the classification into three levels:
  - *Level 1*: An adaptation of the models of Berniker [4] (used also by Pfleeger [19]): It was extended by two new models, i.e., the cooperative and education models on the highest level. In contrast, the rule model [28] (which is transversal and simply means that TT is enforced), the organisational model, and the informal cooperation from the cooperative model were excluded because they were out of our scope.
  - *Level 2*: Groups of medium types, each belonging to a specific model.
  - *Level 3*: The single mediums collected in the literature
- Reviewing each other's classifications and building the final classification.

The first two levels of the classification are shown in Tab. IV. We provide the full list of mediums and literature references online [27]. In a subsequent question (*Medium02*), we also asked the participants which transfer mediums they believed to be best for which specific transfer objects.

TABLE IV: Classification of mediums

Models (1st level)	Medium categories (2nd level)
People-mover model [4]	Personal exchange
Communication model [4]	Publications
	Internet resources
	Conferences, workshops, etc.
	Guidelines
Vendor model [4]	Consultancy
On-the-shelf model [4]	Software, systems, and tools
	Standards
Cooperative model	Co-working
	Licensing
	Research cooperation
Educational model	Educational programs

c) SG3 - Improvements: We collected indicators for improving TT in the continuation of the projects. The main focus was on the goals for TT. We asked this via an open question for two reasons: (1) to check whether goals are the same as motivations (*ImpF01*), and (2) to understand how to support transfer activities in follow-up projects with measurements (*ImpF02 to 05*).

III. SURVEY RESULTS

The survey was open from 12th of March until 30th of April 2014 and disseminated via the mailing lists of the two participating projects. In the middle of the survey period, we additionally sent a reminder to the same mailing lists.

In total, we collected 45 responses to our survey, but only 49% of them completed the survey. Since we spread the survey via a project mailing lists and we don't know the exact number of addressees, we cannot provide a response rate. About 40% of our overall respondents answered after the reminder mail (n=18). Most of the non-complete responses (n=23) aborted the survey at the beginning (Introduction: n=8; Company profile: n=3) and in the current-state description (n=11). In the following, we will only refer to the data set of the completed survey (n=22). In addition to the textual description of all the different results, we summarized all results in Fig. 2. This offers a graphical overview of the transfer motivations, objects, mediums, triggers, and the time to transfer.

For each investigated aspect, we present the overall results as well as segmentation by organisation type (academia vs. industry, *C_Prof02*), and by organisation size (*C_Prof01*): large organisations, i.e., more than 500 employees vs. small to medium, i.e., less than 500 employees. We did not split the results into roles, qualifications, or other possible variation factors due to the small number of answers for each category.

A. Demographics

In our respondents sample (*C_Prof02*), 63% of participants work in industry (n=14) and 37% in academia (n=8). All academia respondents came from either universities or applied research institutes such as Fraunhofer (both 18%, n=4). The industry partners came from development companies (54%, n=12), almost equally from research units (32%, n=7) and business units (27%, n=6) in those companies.

Our results cover a broad rage application domains (*C_Prof03*): 27% from automotive (n=6), 14% from avionics (n=3), 23% from automation (n=5), 14% from railway (n=3) and others. The respondents of our survey work in companies of different sizes (*C_Prof01*): 68% of them are working in companies with more than 500 employees (n=15). We classify all the others as small and medium enterprises (n=7).

The roles that our respondents hold (*P_Prof01*) range from requirements engineer, architect, developer, quality engineer to testers. In addition to these roles, the sample also includes product managers, process engineers, decision makers, and researchers both from academia and industrial research units (but mainly from the former). Based on the academic qualifications (*P_Prof02*), our sample is composed of 36% PhDs (n=8), 46% respondents with a Diploma[5] (n=10), and 18% with a Master's degree (n=4).

Regarding the TT specification presented above, our sample contains both TT roles (*P_Prof05*) given in the TT definition: 32% (n=7) perform both roles, 59% (n=13) classified themselves exclusively as transferors, and 9% (n=2) exclusively as transferees. Most of the participants performing both are from company research units because they are transferees when receiving technologies from outside, e.g., from academia, and transferors when they transfer technologies inside their company, e.g. to the companies' business units.

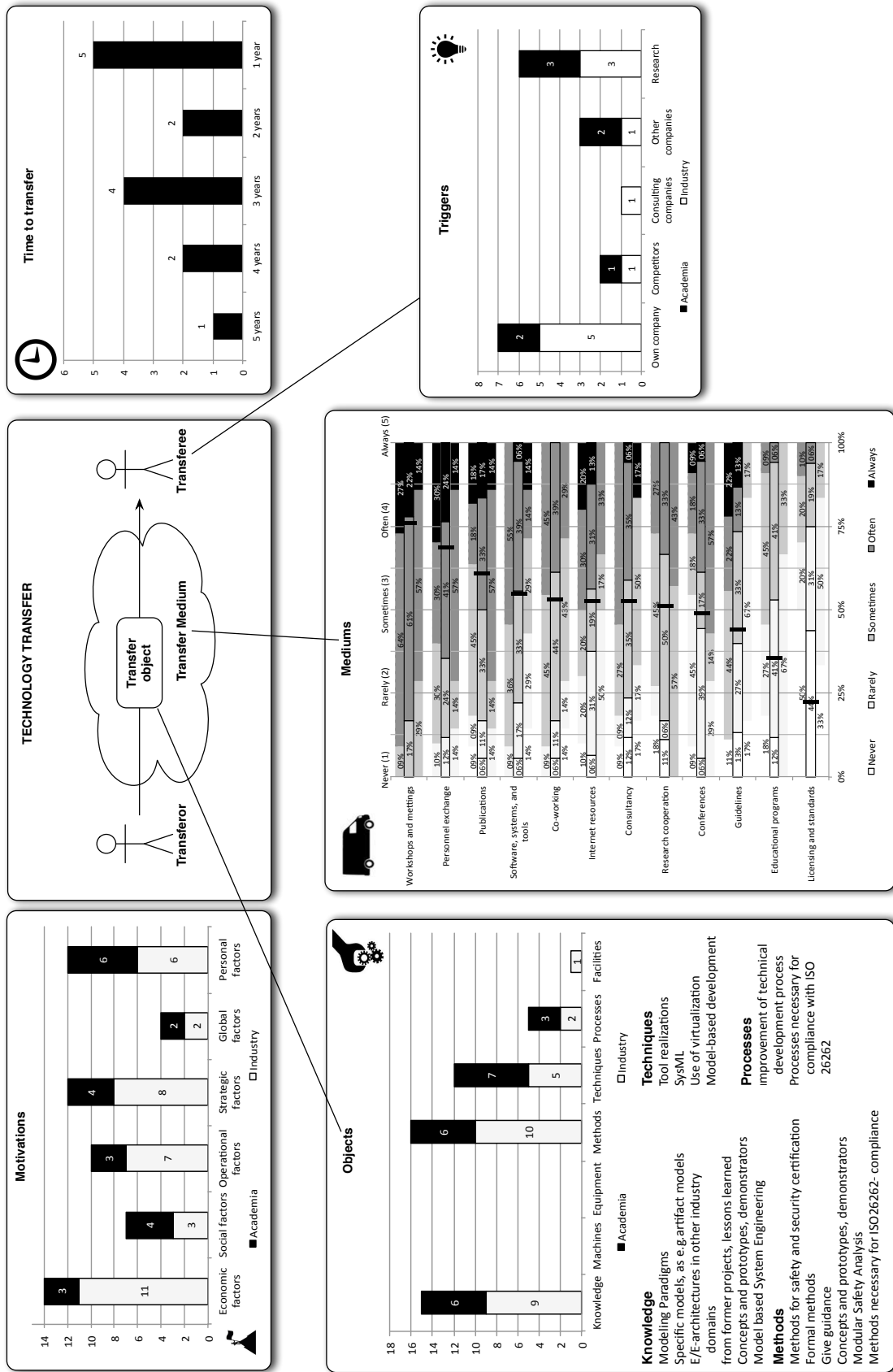[5]German university degree, equivalent to Master's degree

Fig. 2: Characterization of the technology transfer in the two projects studied

B. SG1: Current state of TT

We present descriptive statistics on each of the five aspects investigated in the following paragraphs.

1) Motivation:

Overall: Among all our responses we found different motivations for TT (*Transfer01*, Fig.2). Given that this question was a multiple choice question, the percentage values in the results add up to more than 100%. The 78% of all responses listed *economic factors* as one of their motivations (n=14). This is followed by strategic and personal factors with 67% each (n=12). With 56%, operational factors are mentioned by more than half of the participants (n=10). Social factors (39%, n=7) and *global factors* (22%, n=4) were mentioned less often. *Organisation Type*: Within the industry segment, all the factors are the same as in the overall analysis, but personal factors (n=6) are the least frequently stated one of the top four. All (n=11) industrial participants mentioned *economic factors*. In contrast for the academic perspective, *personal factors* were mentioned most frequently (n=6). *Economic factors* as well as *operational factors* are in the second to the last position (n=3). Similar to the overall and industrial results, *global factors* were mentioned least often (n=2).

Organisation Size: For large organisations, the most mentioned frequently factors are the same four as in the overall set. The difference is that *operational*, *strategic*, and *personal factors* are on the same level (n=8). All large organisations (n=13) mentioned *economic factors*. In contrast, in SMEs *strategic* and *personal factors* are most often cited motivations (n=4). The other factors are on a low level (n=1 or n=2).

2) Transfer objects:

Overall: Within the different transfer objects given in the TT definition (*Transfer02*), there is a wide gap between three very often used objects and the others (see also Fig. 2, bottom left). The most frequently transferred objects belong to the categories *methods*, mentioned in 89% (n=16) of the responses, *knowledge* in 83% (n=15) and *techniques* in 67% (n=12) of responses. The two remaining transfer objects mentioned are *processes* by 28% of the respondents (n=5) and *facilities* by 2% (n=1). *Machines* as well as *equipment* were not mentioned. Some of the participants also clarified in detail which objects are transferred (or would like to) using the open question *Transfer02*: *methods for safety and security* were the most frequently mentioned ones, followed by *model based development* and *tools or prototypes*. One answer was not taken into account because it was too general (i.e., "want to learn about practical problem").

Organisation Type: The industry viewpoint shows exactly the same distribution as the overall results. In the academic answers, *techniques* (n=7) exceed *knowledge* as well as *methods* (both n=6). *Processes* are not that important (n=3) and *facilities* were not mentioned by participants from academia.

3) Process: 80% of the respondents (n=14) answered the open question about explicit process transfer (*Transfer04*), three of them from SMEs. Most of the answers were not taken into consideration for the following reasons: one declared the question could not be understood; others answered by just listing the mediums used; two participants answered that there is no dedicated transfer because, either the case study is still in a preliminary phase, or the case studies proposed by industry are much more complex than the capabilities of the academic tools (answer provided by an SME); other answers were quite general, e.g., "Dedicated transfer process" without further details; another person answered citing consulting activities but without any explicit link to the transfer process. As a consequence, only subsequent four answers were informative for the sake of our investigation:

- "At the beginning of a research/pre-development project an agreement on the transfer objects is signed by both sides. Progress is continuously monitored and finally the transferee confirms successful completion and transfer. If and how the transfer object is used by the transferee is not part of the transfer process."
- "Needs for action are identified in the organisation. Possible transfer objects are identified. Transfer objects are modified, so they fit to our internal processes. Objects are applied in pilot projects. Objects are integrated in internal work instructions."
- "I am not sure whether there is an explicit process. Usually, a result needs to be packaged into a service. This service is promoted by the researcher and business areas managers. They talk to potential customers, or while identifying customers' needs they find that this new thing might be a good solution. However, in most cases the solution has to be adapted to the specific needs of the customer." (answer from a SME).
- "This new thing might be a good solution. However, in most cases the solution has to be adapted to the specific needs of the customer."

A common aspect in all these answers is the importance of customisation of the transfer objects (also via piloting) and the absence of a well-defined step-wise process (except one answer).

4) Time to transfer: The results about time to transfer were already presented in our previous work [10], where we showed that TT duration (*Transfer05*), although strictly dependent on the type of object transferred (n=6), is on average three years. In contrast to the previous publication, we look here only at the completed questionnaires and with a greater level of details in presenting the answers. Fig. 2 shows a smaller average, around two years. Even if this seems to be a short duration, the answers ranged from (several) months to a maximum of ten years. Besides this wide range, the answer of most participants was one year (n=5), which is even lower than the average.

Six respondents stated that the transfer time depends on different transfer objects. In addition to this, five participants also stated a time frame (e.g. "1 to 5 years").

Eleven participants considered years as an appropriate scale, whereas three considered months. Only one respondent considered weeks. For those considering months, one stated "three months", another one "more than six months", and the last one "months to years". The stated number of years ranges from one year to five years. One year was mentioned most often (n=5),

followed by three years (n=4). Two and four years were each stated twice and the longest time frame of five years was given by one respondent. This results in an average of approx. 2.5 years. Out of the 18 respondents, a third (n=6) did not have an answer.

In question *Transfer06*, for 39% of the countable responses (n=7), the transfer time reported in *Transfer05* is fine, while 22% would like to have a shorter transfer time (n=4) and only 1 respondent thinks that the transfer time should be longer (this person answered *Transfer05* with "3 to 4 years"). The respondents who are fine with the transfer time reported a value ranging from 1 to 5 years (mode=1). The participants who would like faster transfer reported a shorter time range in *Transfer05*, i.e., from months to at most 3 years. The remaining 33% of the respondents (n=6) did not know the answer to this question.

In addition to the duration, we elicited how often new transfer objects are transferred from one organisation to another (*Transfer07* and *Transfer08*). Half of the transferors reported a frequency of at least once a month, the others at least once a year and only one participant answered once a day. The transferees focus more on the longer term, because 60% of all respondents receive objects at least once a year and only 20% at least every month or every week, respectively.

5) Triggers (only for transferees):
Overall: Triggers for technology transfer (*Transfer09*) come from within the own organisation in 78% of the answers (n=7) and from research institutes in 67% (n=6), followed by other organisations (33%, n=3) and competitors (22%, n=2), whereas consulting (11%, n=1) was mentioned only once.
Organisation Type: The segmentation into industry and academic partners showed that industry acquires knowledge mainly from within their own organisation (n=5) and from research institutions (n=3). The other three trigger provenances were mentioned only once.
Organisation Size: The only appreciable difference to the overall as well as to the different organisation types is that smaller organisations get more triggers from competitors.

C. SG2: Transfer Mediums

Overall: At the bottom of Figure 2, mediums are ordered based on their usage, which means the one with the highest average (tagged by the black mark) regarding the usage is at the top and the lowest at the bottom. The average of the top three mediums is: workshops and meetings μ=4.06, personnel exchanges μ=3.76, and publications μ=3.44, i.e., between "often" and "sometimes". These top items are followed by six mediums with an average of around 3.0 (between 3.22 and 2.94). For the remaining three transfer mediums, the lowest one is licensing and standards with μ=1.88 and a large gap to the others. The first preliminary analysis [10] showed that the most frequently used mediums are human-intensive, e.g. personnel exchange or workshop, whereas artefact-based mediums, e.g. standards, are used less often.

In addition to the results of the usage on the transfer mediums, we had two open questions for transfer mediums (*Transfer03* and *Medium02*). From *Transfer03* we extracted 29 mediums overall, 18 of them classified as human intensive and 11 as artefact based. This additionally supports the findings of the closed question (*Medium01*, [10]) presented above.

From *Medium02*, we collected the following suggestions:
- Personnel Exchange, Publications, Workshops & Meetings *for* Knowledge
- Personnel Exchange, Workshop & Meetings (n=2), Guidelines, Consultancy (n=2), Software, Systems and Tools *for* Methods
- Workshop & Meetings *for* Processes
- Workshop & Meetings *for* Tools

We observe again the prevalence of the human-intensive mediums over artefact-based ones (n=9 vs n=3), and we observe that one participant considered "tools" as an object and not only as a medium. We did not include answers that were too general; however, we report them because they also support the prevalence of human-intensive mediums:
- "Successful transfer absolutely requires personal contact with the transferees."
- "Workshops and meetings are suited for all transfer objects (no hard transfer criteria though); personnel exchange for knowledge, guidelines for methods"
- "Depends on the audience and objective. Needs to be decided from case to case due to the fact that more than 10.000 employees in different countries need to be trained."
- "Consultancy for everything. Without talking to the people, you do not get their specific problem. I am not a traveling salesman, trying to sell my dots to who ever I meet. We try to understand their problems, then develop a solution, and perhaps one or more explicit objects are used."

Organisation Type: Looking only at the results of the industrial companies, there are two differences compared to the overall data set. One of them is that the guidelines are ranked notably higher (μ=3.44) than in the overall results (μ=2.87). The other difference is a lower value (μ=3.27 versus 3.44) for the publications.

In contrast, for academia and the ordering / importance of their transfer mediums, guidelines are ranked as second lowest (μ=2.0) and research cooperations (μ=3.43) as well as conferences (μ=3.29) are notably higher than in the overall and industry segments.

Organisation Size: The data shows that in large organisations, personnel exchange, publications, workshops, and meetings as well as co-working have high values ($\mu \geq$3.4). In contrast, for the small and medium sized organisations, besides the workshops and meetings (μ=4.23), which are ranked the highest, nine of the remaining eleven mediums are ranked in a small range (between 3.6 and 3.0).

D. SG3: Improvements

Out of the nine open answers we received regarding the goals, we discarded three because they were too general (e.g.,

"Technology transfer"). The remaining six were all about specific operational goals in SPES XT project except for one, which was an economic goal.

The next step following the definition of the goals for TT is the determination of measurements to check the TT effectiveness with respect to the goals previously defined (*ImpF02*). Here, the results of the participants deviate very much: empirical studies, comparative analysis, pilot projects, revenue, expert judgments (n=2), or a simple binary variable on transfer. Question *ImpF03* investigates whether methodically collect empirical evidence would help to support TT: 78% of the nine participants answered that empirical evidence, such as experiments or case studies, would help in the decision making process regarding transfer of a particular object.

Finally, only one respondent was interested in a TT project with explicit measurement goals (*ImpF04*) (indicating internal company-wide exploitation) and four people signalised their interest in conducting follow-up interviews (*Concl02*).

IV. Resulting Theory & Relation to Existing Evidence

Based on the results we reported in Sect. III, we now induce a set of research hypotheses which constitute a first step towards the construction of a framework to characterise how technology transfer takes place in SE research projects with both academic and industrial partners involved.

A. H_1: The technologies developed in SE research projects are not mature enough for direct application but need strong customisation to fit the industrial contexts.

In our answer sample, respondents reported on the need of customisation of the transfer object to fit the context needs, which, paradoxically, decreases the external validity of the technological solution. Hence, an important and practical implication for us is to understand which techniques developed in research projects can be adopted as they are and which encounter barriers to the adoption so that customisation is required (potentially as an own self-contained TT project). We are already verifying in more detail this hypothesis by currently conducting another survey on the barriers to the transfer to practice. In that survey, we also conduct a partial replication of an assessment of barriers and benefits of model-driven development adoption in Italy [26] and we aim at a comparison of the results in the light of this research hypothesis to further scale up to practice.

B. H_2: The standard model of representing TT as a transaction of an object that occurs from a transferor to a transferee does not fit reality.

An interesting and at the same time challenging aspect that emerged from the answers in the survey concerns the roles involved in TT. Many of our respondents identified themselves on both sides, i.e. as transferors and as transferees. The model we have used, although with some simplifications, is based on (and coherent to) currently used models and taxonomies from literature (e.g., [21] and [5], and for further details see [10]).

However, we believe that this way of modelling TT is not precise enough to capture the complexity of the interactions involved in the transfer. For example, Aoyama et al. [1] created a more complex model that involves also intermediate roles ("brokers") and feedback loops; but even with this refinement, roles are still too static and linked to the metaphor of transfer, which might be obsolete. For instance, a better concept might be found starting from the idea of "Knowledge Circulation" which is used by European institutions (see, for instance, [11, pp. 121-199]). Further empirical evidence in favour of this hypothesis could motivate the need of a more precise and specific model to SE research, and even a new metaphor or concept which goes beyond the idea of a "transfer". Such a model can serve as a conceptual framework to provide better support for same or similar studies.

C. H_3: Technology transfer takes place without an explicit process.

Another important point revealed by the answers to the survey is the lack of explicit processes for TT going beyond the formalities and best practices linked to the setting of establishing research collaborations between academia and industry (see, for example [15]). Also, some respondents reported informal ways to conduct a transfer; we know, for example, from literature that informal transfer occurs more likely in case of spatial proximity [12]. Based on this initial data we collected, we refined and extended our mediums classification (see Tab. IV). In detail, we added the category *Informal transfer* to the model, and added also five third-level mediums, which were reported in the open question, i.e. web meetings, presentations, talks, movies, and coaching. In addition, the answers to the frequency of the transfer reveal that TT is not perceived as a continuos process especially by the transferees. In SE research, an example for complex process for TT is the one of Gorschek et al. [13]. In their 7-step process, the validation of the solution plays an important role, both in terms of in-vitro experiments in an academic set-up as well as in-vivo through piloting in real industrial contexts. However, a key question arises here: "*What could be the benefits of having a dedicated and formalised TT process?*". Therefore we believe that it is important to understand whether other research projects have an explicit process for TT, and what are the consequences of having (and applying) / not having it.

D. H_4: Industrial organisations gain new knowledge mainly within their own confines.

Additionally, we have seen that triggers for new ideas for industrial participants come mostly from within the organisations' own confines. This is a surprising fact, given that there is evidence that external knowledge has a positive impact on product development and innovation (see, e.g. [16], [23]). By looking at the small and medium-sized organisations, the triggers come more often from competitors ideas. An explanation of the latter point could come from the Gatekeeping theory [18] and its recent evolutions [2], which state that

knowledge in smaller organisations might have to traverse fewer gates and channels. We believe that this hypothesis should be further investigated in multiple settings to verify when and why it happens, and which are the implications for the success of a transfer.

E. H_5: Most used transfer mediums are human-intensive.

As we already discussed in our previous publication of the preliminary results [10], human-intensive mediums are used much more often than artefact-based ones. However, when looking at the variation factors, guidelines, which are artefact-based and developed on purpose for the projects [14], are used more often by the industry partners. Finally, it is relevant to report that patents and standards, despite their widespread use as a measure of the effectiveness of TT, are used less often in these projects, which is in tune with what seems to be happening in the IT sector [24]. In our current survey on the barriers to the adoption of the SPES_XT technologies, we are also investigating this hypothesis by looking at the usage and effectiveness of the different mediums to understand which are the best possible strategies to disseminate the results for different stakeholders and in different contexts.

F. H_6: The motivations that drive the transfer in industry and academia are heterogenous.

We could observe that the motivations for transfer heavily differ between industry and academic organisations; as expected, however, with prevalence of economic and strategic motivations in the first case, and more personal reasons (e.g., intellectual growth) in the second case. In both cases, motivations are different from the goals, which are mainly at operational level. These cultural differences between academia and industry are historically known as the problem of the "*The Republic of Science* vs *The Realm of Technology*" [8], which can create barriers to collaboration and limit the transfer success [7]. One example is the diversity of the rewards systems and practices of disclosing results in the two sectors [24]. Supporting or rejecting this hypothesis also in the SE field is important to leverage as much as possible the motivations of the research partners.

G. Revised definition for Technology Transfer

Based on our observations and follow-up stated hypothesis, we reworked the original definition of TT [25] resulting in a new one, which should fit better what we expect to hold for SE, also in relation to the aspects investigated. Tab. V shows the (re-)definition. The most important differences with the original definition are:
1) We introduced the concept of sustainable adaptation of an object by a technology recipient for a specific purpose, to stress the need of adoption (tailoring and usage) in a specific context (see H_1)
2) We removed the concept of a transaction between a transferor and a transferee in favour of a more generic sharing and developing of a technology object between actors, to add flexibility and reflect better reality. Please

note that the technology recipient from previous point can be external to the actors (see H_2, H_3, H_4)
3) We made the objects[6] and the mediums[7] (see H_5) explicit

This new definition has not to be intended as final but as a starting point to be refined with the verification of the research hypotheses we have set up, or the verification of additional ones from independent assessments.

V. THREATS TO VALIDITY

Internal Validity. The simplified model used for representing TT permitted reducing the risk of different mental models among participants, thus reducing the corresponding threats. However, it does not fully capture all the complex interactions between transferors and transferees and the dynamics of the whole TT process (as the imbalanced distribution of TT roles suggests), by, e.g., using an outdated linear model for technology push. We tried to mitigate this threat in two ways: with an explicit (optional) open question for describing the process[8] and by collecting a comprehensive list of mediums [27] of which some might break the linearity of such model (e.g. "research cooperations'"). Also, we started a more systematic literature review of the existing TT models with the aim to improve them with a more comprehensive conceptual framework in future work. This is even the case why we revised the definition of technology transfer in SE.

Another important threat is represented by the low response rate. Given that only 22 participants filled out the questionnaire, we might have missed some information, and answers might not be fully representative of the actual transfer in the projects. However, we do not exactly know what our target population is, i.e., the number of participants in ARAMIS and SPEX-XT who are actively involved in transferring the developed techniques. We could only control this threat in the current study in the way of sending one reminder to the mailing list, but we aim at improving the response rate with the follow-up survey by specifically contacting the different project partners.

External Validity. We are aware of the fact that TT is a process that can largely vary from case to case in different contexts. Therefore, the scope of validity of this survey is limited to the two German national projects ARAMIS and SPES_XT, and more specifically to the area of model-driven development for embedded systems covered by these two projects. Nonetheless, the focus of this survey was to generate testable hypotheses which can be already used to steer future research in that direction. These hypotheses can then be also used to be validated in different other domains to get generalizable results.

VI. CONCLUSIONS AND FUTURE WORK

In this study, we undertook a first step towards the construction of a framework to characterise how technology transfer takes place in SE research projects with both academic

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[6]In SE, the objects are knowledge, methods, techniques, and processes
[7]The classification of mediums [27] can be used as initial list of mediums.
[8]However, we did not find any structured process.

TABLE V: Redefining Technology Transfer

Technology transfer is the process of sharing...	
(Old definition)	(New definition)
knowledge, machines, equipment, methods, tools, techniques, processes, and facilities with the aim of facilitating accessibility of scientific and technological developments from primary discoverers or transferors to potential users or transferees/recipients, who will exploit the technology into new products,processes, applications, and business models.	or developing a technology object between two or more actors via one or more mediums so that the technology recipient sustainably adopts the object in the recipient's context in order to evidently achieve a specific purpose.

and industrial partners involved. To do that, we studied the technology transfer in two large German research projects on model-driven SE technologies in the context of embedded systems. Taking as a reference a basic conceptual model of technology transfer, we observed how industry and academia interacted in the transfer of the developed technologies. Due to the exploratory nature of the work and to the low number of respondents, our main goal was no to find statistically significant results, but rather to extract from our observations a set of hypotheses as a basis for follow up work, also in the sense of a collaboratively effort of the community to fill the gap of poor empirical evidence on the assessment of technology transfer in SE research. Therefore in our study, we also identified and discussed some issues when applying the traditional definition of TT to SE and finally created a new more SE-specific version.

Our next step is to verify the research hypotheses formulated during the results analysis in follow-up studies. Necessary condition for such a goal will be to break them down into statistical hypotheses, testable through empirical studies. We would like also to extend the initial set of hypotheses with the contribution of other researchers.

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