A Study and Comparison of Industrial vs. Academic Software Product Line Research Published at SPLC*

Rick Rabiser
CDL MEVSS
Johannes Kepler University
Linz, Austria
rick.rabiser@jku.at

Klaus Schmid
University of Hildesheim
Hildesheim, Germany
schmid@sse.uni-hildesheim.de

Martin Becker
Fraunhofer IESE
Kaiserslautern, Germany
martin.becker@iese.fraunhofer.de

Goetz Botterweck
Lero, University of Limerick
Limerick, Ireland
goetz.botterweck@lero.ie

Matthias Galster
University of Canterbury
Christchurch, New Zealand
mgalster@ieee.org

Iris Groher
Johannes Kepler University
Linz, Austria
iris.groher@jku.at

Danny Weyns
KU Leuven, Belgium
Linnaeus Univ., Sweden
danny.weyns@gmail.com

ABSTRACT

The study presented in this paper aims to provide evidence for the hypothesis that software product line research has been changing and that the works in industry and academia have diverged over time. We analysed a subset (140) of all (593) papers published at the Software Product Line Conference (SPLC) until 2017. The subset was randomly selected to cover all years as well as types of papers. We assessed the research type of the papers (academic or industry), the kind of evaluation (application example, empirical, etc.), and the application domain. Also, we assessed which product line life-cycle phases, development practices, and topics the papers address. We present an analysis of the topics covered by academic vs. industry research and discuss the evolution of these topics and their relation over the years. We also discuss implications for researchers and practitioners. We conclude that even though several topics have received more attention than others, academic and industry research on software product lines are actually rather in line with each other.

CCS CONCEPTS

• **Software and its engineering** → *Software product lines*;

KEYWORDS

Software product lines, industry, academia, SPLC

ACM Reference format:
Rick Rabiser, Klaus Schmid, Martin Becker, Goetz Botterweck, Matthias Galster, Iris Groher, and Danny Weyns. 2018. A Study and Comparison of Industrial vs. Academic Software Product Line Research Published at SPLC. In *Proceedings of 22nd International Systems and Software Product Line Conference, Gothenburg, Sweden, September 10–14, 2018 (SPLC '18),* 11 pages.
https://doi.org/10.1145/3233027.3233028

*The first author coordinated the efforts presented in this paper; the second author created the initial concept; all other authors contributed equally/are listed alphabetically.

SPLC '18, September 10–14, 2018, Gothenburg, Sweden

ACM ISBN 978-1-4503-6464-5/18/09…$15.00
https://doi.org/10.1145/3233027.3233028

1 INTRODUCTION

Based on initial ideas touted as program families in the 1970s by David Parnas [23], Software Product Lines (SPLs) have become a widely investigated research area, especially since the 1990s. Early workshops and conferences focusing on SPLs (or Software Product Families, as they used to be called in European venues and projects), eventually led to the International Software Product Line Conference (SPLC)[1].

Early SPL research conducted in Europe was driven mainly by industry needs and big research projects with many industrial partners, such as the Esaps and Cafe projects [34]. Early SPL research conducted in the USA was mainly driven by the Software Engineering Institute (SEI) at Carnegie Mellon University and the needs of their industry and government partners [22]. Over the years, the field diversified and more and more academics as well as practitioners from industry started to conduct research on SPLs with different aims and outcomes. Several systematic literature reviews and surveys show the large amount of research that has been published on diverse topics related to SPLs [1, 2, 7, 11, 14, 15, 27, 28, 30]. From the initial single-track model, over the years several new conference tracks emerged at SPLC to cover the diversity of research types, e.g., research, industry, systems engineering, and vision tracks.

Researchers from both academia and industry contributed diverse types of papers (e.g., full research papers, position papers, or experience papers), with diverse types of content and evaluation (e.g., examples, empirical evaluations, industrial applications), focusing on diverse application domains, in total resulting in 593 peer-reviewed papers published at the main SPLC events until 2017 (not counting session reports, keynotes, and extended abstracts). Additionally, many SPL-focused papers have also appeared in other conferences – such as ICSE, ESEC/FSE, ESEM, WICSA, GPCE, ASE – and journals – such as TSE, TOSEM, JSS, IST – as well as textbooks, edited books, and technical reports (see the systematic literature reviews and surveys cited above for a good overview). Still, the most SPL-related publications can be found at SPLC.

The authors of this paper have participated in many SPLC events over the years, some even attended the pioneering workshops in the 1990s. Also, we have been involved in a plethora of projects, both with industry and purely academic, focusing on SPLs. Over

[1]http://splc.net/history

the past few years, we frequently discussed the hypothesis that SPL research has been changing. In particular, research conducted in industry and academia seems to be quite different and (in contrast to the early days of SPL research) increasingly does not seem to align anymore. However, there is no scientific evidence that there is, in fact, a (potentially increasing) gap between research done in academia and industry.

The gap between research and practice has been investigated for the overall field of software engineering [16] before. Earlier work in the field of SPLs has collected existing case studies [21] and has assessed the use of particular variability modelling languages and tools in industry [4]. Multiple systematic literature reviews and surveys [1, 2, 7, 11, 14, 15, 27, 28, 30] provide an overview of the SPL research field. However, to the best of our knowledge, no study has been conducted to assess the development of research – i.e., the topics addressed – in academia vs. industry over the years in this field. With this study we aim to fill this gap.

The **goal** of this paper is to provide evidence to *confirm or refute the hypothesis that the work on SPLs in industry and academia is increasingly drifting apart.* It is important to note that our study does not aim to judge on such a trend, but only to determine whether it actually exists and in which directions it is going. As a starting point, we assessed a considerable subset of papers (140) published at SPLC (from 1996-2017), randomly selected but ensuring a good spread over all years and tracks (especially research vs. industry). Specifically, we aim to answer the following **research questions**:

RQ1: *Do phases, activities, and topics addressed in academic and industry SPL research align?*

RQ2: *How did studied phases, activities, and topics in industry and academic SPL research evolve over time?*

For RQ1, we aim to compare SPL research in industry and academia, i.e., what phases (domain engineering, application engineering), activities (requirements engineering, design, implementation, etc.), and topics (variability management and modelling, tools, etc.) are addressed in academic vs. industry research. Details on phases, activities, and topics are described below, as part of our research approach. For RQ2, we want to find out whether the addressed phases, activities, and topics changed over time (and how) in industry and academic research. We are also interested in whether the phases, activities, and topics addressed in industry and academic research developed and evolved in the same/a similar way.

This paper provides the following **contributions**:

- A detailed list of SPL phases, activities, and topics addressed by academic and industry research over the years.
- An assessment of the coverage and relation of these phases, activities, and topics by/in different types of research in academia and industry.
- An overview of the development and evolution of the phases, activities, and topics covered over the years.
- A research methodology to assess the alignment of academic and industry research in the area of SPL. This methodology can be used for further investigations covering more publications, especially from other venues to extend the evidence we provide in this paper.

Multiple publications argue for the importance of research focusing on, or being driven by, topics relevant (also) in industry [6] and discuss the opportunities and risks of academia-industry collaborations [12, 39]. With our work, we do not aim to discuss this (again), but want to uncover existing trends in the field of SPLs and provide a scientific basis for further discussions. For example, a positive interpretation of less industry-focused or industry-driven research could be that research work becomes increasingly visionary. Thus, we accept that there may be various different interpretations of the evidence identified in this paper. Both researchers and practitioners can benefit from the clearer picture of the current state and the historical development of SPL research in academia vs. industry we provide in this paper, e.g., to focus their ongoing or planned research based on trends and gaps identified in our study.

2 RESEARCH APPROACH

To address the research questions, we followed the iterative approach depicted in Figure 1. In the first phase, we *developed a study concept* to outline goals, context and research questions of our study. After multiple discussions and refinements, we detailed the goal, context, research questions, and processes (especially data extraction and synthesis) in a *research protocol.* As described in this protocol, the *goal* of our study is to *assess the research conducted in the field of SPLs* to find out what phases, activities and topics are addressed, whether phases, activities and topics addressed by industry and academia are related, and how the phases, activities and topics addressed in industry and academic research evolved over time, with the main aim *to identify trends and the differences between academic and industry research.* The *context* of our study is research on SPLs, in this paper represented by 140 publications at SPLC from 1996-2017.

We have presented our research questions above; here we discuss the development of the SPL phases, activities, and topics we used to categorise the SPL research and the development of our data extraction form (cf. left half of Figure 1), and the data extraction and synthesis processes (cf. right half of Figure 1). Please find our study material, including detailed definitions of key terms, online (see [26]). While our approach partly resembles that of a systematic mapping study [25] — e.g., regarding the definition of a research protocol and data extraction — we did not use search terms to select primary studies (as we had SPLC as the focus venue) and solely decided on inclusion/exclusion using random selection (ensuring distribution over different tracks).

2.1 SPL Phases, Activities and Topics

We developed a list of SPL phases, activities, and topics in several iterations (with discussions and refinements). This is based on our own previous experiences, e.g., [3, 5, 8, 11, 28, 29], and also on frameworks like the Family Evaluation Framework (FEF) [35] and the SEI Framework for Product Line Practice (PLP) [2]. While we used many sources as input, the main focus was to adequately and completely represent the various phases, activities, and topics addressed in SPL research. Therefore, the level of detail of the

[2]https://www.sei.cmu.edu/productlines/frame_report/introduction.htm

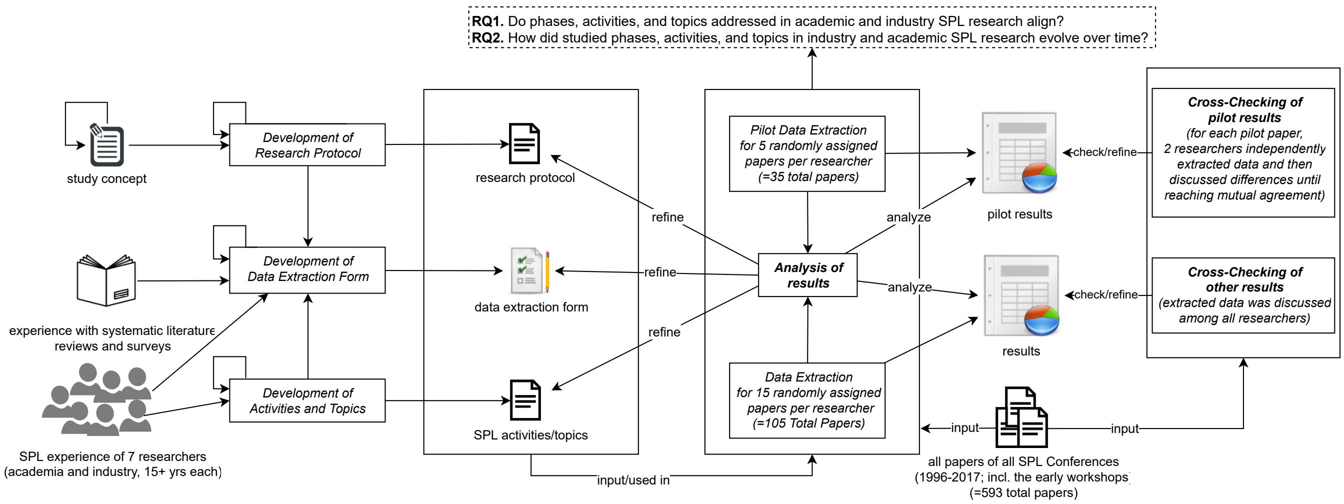

Figure 1: Research approach.

categorisation varies among phases, activities and topics, i.e., some topics are described in more detail than others to cover more fine-grained insights.

We provide definitions for each phase, activity and topic in an online document (see [26]); an overview is given in Table 1.

As described in more detail below, the main structure of our data collection form is as follows: It starts with some descriptive information like the author and conference. Then a brief characterisation of the paper (e.g., whether it is academic or industry research) is given. The content is then characterised in two steps. First, phases and activities are identified. This includes the differentiation between phases application and domain engineering. The structure is strongly influenced by the FEF and the PLP, with some additions and simplifications. Second, as we had the impression that an activity-based view is insufficient, we decided also to collect further topics, which are summarised in the last two columns of Figure 1. These were strongly influenced by our understanding of topics commonly addressed in research, with a corresponding refinement of heavily researched topics (e.g., variability), while other areas are only addressed in broad terms.

2.2 Data Extraction Form

We used Google Forms (see [26]) to capture the data extracted from papers published at SPLC.The final form (refined iteratively as described in the next subsection) comprises two parts.

Part 1 was used for capturing general information about each paper (title, authors, conference) as well as categorising its research types, evaluation type, and application domain. For the complete list of application domains and evaluation types we refer the reader to Section 3. In part 1, we also performed an author classification based on authors' affiliation as specified in the paper, i.e., whether an author can be considered as from academia or from industry. Industry includes companies but also research departments in companies. Authors working at organisations predominantly undertaking academic research (e.g., Fraunhofer, SINTEF, VTT) were counted as academic authors.

Regarding research type, we count a paper as *academic research* if the work presented in the paper has been performed without any clear connection to industry, e.g., only toy examples or experiments made up by academics are shown in the paper. We count a paper as *industry research* if it is clearly motivated by industrial challenges and discusses how to solve these challenges in practice or if it evaluates a presented approach, method, or tool in/with industry, e.g., in an empirical evaluation or even a full-scale industrial application. A paper that only uses examples from industry but otherwise clearly presents research that has been performed in academia still counts as academic research. In case it is hard to categorise a paper as academic or industry paper, we included the option "unclear" in the data extraction form (including a textual comment for details). While other approaches to categorising papers are clearly possible — e.g., based on content, motivation, and solution — they are all rather subjective and we used the evaluation/application presented in a paper (plus the track it was published in) as it provides a good indication of a paper's focus.

Part 2 of our form was used for capturing the phases, activities and topics (as described above) a paper focuses on. Additionally, a free-text field allowed each data extractor to add details on one or several of the topics (e.g., to add what non-functional properties or tools are described in a paper) as well as arbitrary other comments, e.g., to suggest additional topics. Table 1 summarises what information we captured. Details can be found online [26].

2.3 Data Extraction and Synthesis

We started with performing a *pre-pilot*: Two researchers test-drove the form by reading one randomly selected SPLC paper and extracted data together. Their feedback was used to discuss and refine the form, which was then used in a *pilot* to extract data from 35 papers randomly selected from all SPLC publications, but ensuring a good spread over all years and coverage of both research and industry tracks. Specifically, in the pilot phase, each of the seven authors of this paper used the form to extract data from 5 papers and documented any issues. These issues and the extracted data

Table 1: Data extracted from each paper (Details can be found online [26]).

Descriptive Information
- Venue
- Year
- Authors
- #Authors
- #Industry Authors
- #Academic Authors
- Title
- Track (Research, Industry, Experience, Systems Engineering, Vision, Single Track)

Characterisation
- Application Domain (...)
- Paper type (academic research, industry research, unclear)
- Type of Evaluation[38] (...)
- Comments (*freetext*)
- Study Motivation (*freetext*)

*Life-Cycle **Phases*** (Domain Eng. (DE), Application Eng. (AE), DE-AE Sync.)

*Development Practices/**Activities***
- Business Case Definition
- Scoping
- Requirements Engineering
- Architecting
- Detailed Design
- Implementation
- Product Configuration
- Product Derivation/Instantiation
- Verification
- Validation (Testing)
- Validation (Product Certification)
- Configuration /Release Management
- Deployment
- Operation
- Maintenance / Evolution
- Project Management AE/DE

*Other (Cross-Cutting) **Topics***
- Non-SE Activities
  - Outside of Engineering (marketing, etc.)
  - Other Engineering, e.g., Systems Engineering (beyond software)
  - Product Line Learning and Adoption, Institutionalisation
- Organisation
- Financing
- PLE Process Definition
- Variability
  - Variability Management
  - Variability Analysis
  - Variability Modelling (Feature Modelling, Decision Modelling, Other Modelling)
  - Variability-Asset Relation/Mapping
  - Variability Resolution
  - Variability Target (Functional, Non-functional/quality)

- Artefacts
  - Sales Documents
  - Requirements Documents
  - Architecture Description
  - Source Code
  - Build System
  - Tests
  - Documentation
  - Others
- Re-&Reverse Engineering
  - Asset Mining
  - Variability Mining / Rev. Eng. of Variability
- Legacy Products
- Ecosystems / Multi Product Lines
- Runtime adaptation / Dynamic SPLs
- Non-functional Properties
- Tools
- Product Line Metrics

was then discussed in the overall group and used to refine the form further. Then, in the *cross-checking phase*, each of the 35 papers from the pilot was assigned to a different researcher. Each researcher extracted data independently from the first phase and again documented any issues. The data extracted in the cross-checking phase was then compared with the data extracted in the pilot. Any issues were discussed and resolved pairwise, e.g., lists of phases, activities and topics were consolidated and the research type and evaluation type was adapted in some cases to reach mutual agreement. This also led to final adaptations of the data collection form.

After the pilot and cross-checking, we conducted another *data extraction phase* using the refined form. Each researcher extracted data for a set of another 15 papers that were randomly selected from all SPLC events. The extracted data was discussed among all authors when writing this paper.

In total, we extracted data for 140 papers – 35 from the pilot and 105 from the second data extraction phase – out of a total of 593 SPLC papers. These papers are the basis for the results presented in this paper. Specifically, we aggregated all extracted data in a spreadsheet and performed basic quantitative and comparative data analyses (research types vs. evaluation types, research types vs. application domains, research types vs. phases, activities and topics) as well as some qualitative analyses (based on comments made on paper categorisations and foci as well as our discussions). We present our results separately for each research question below. The raw data is available online [26].

3 RESULTS

The 140 papers we analysed in this paper have been published from 1996 to 2017 with an average of seven papers per year (not counting 1997 and 1999 in which no SPLC events took place). Most papers have been published at SPLC (101 papers), while the remaining 39 papers have been published at the earlier PFE workshop series.

In total, the analysed papers have been written by 412 authors (2.94 authors per paper on average), with 286 authors from academia and 126 authors from industry. In total, 80 papers were written solely by academic authors, 37 papers were written solely by industry authors, and 23 papers present works conducted as collaborations between industry and academia. In total, regarding their research types, we classified 90 papers as academic research and 50 as industry research. For three papers the classification was unclear,

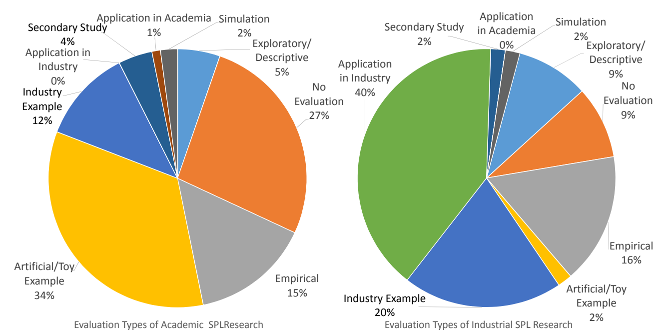

Figure 2: Evaluation types in academic vs. industry research.

i.e., in these papers industry authors present a generic approach and use artificial examples for illustration [13, 18, 32].

3.1 Application Domains and Evaluation Types

Before we go into details regarding our research questions on phases, activities and topics of SPL engineering, we briefly report interesting findings about the application domains and evaluation types of the papers we analysed.

In academia, most research is generic (65%), followed by software and web applications (5%), embedded and software-intensive systems (5%), consumer electronics (3%), automation software (3%), and academia (3%)[3]. Industry research often targets embedded and software-intensive systems (24%) and consumer electronics (10%), followed by automotive (5%), automation software (5%), and cloud- and fog-based systems (5%). 19% of industry research is generic.

Figure 2 presents the types of evaluation in academic research (left) and industry research (right). More than one third (34%) of academic research provides artificial/toy examples only and 27% of the papers do not present any evaluation. This means that 61% of academic research is not properly validated. An empirical evaluation (experiments, case studies, surveys) is provided by 15% and industrial examples are presented by 12% of the academic papers.

[3] Academia as application domain refers to research that focuses on applications in academia (e.g., tools for students/teaching courses).

The predominant type of evaluation in industry research is industrial application (40%). Industry examples are provided in 20% of the papers and empirical evaluation is provided by 16% of the papers. Only 9% of industry research does not provide any evaluation and 2% provide toy examples only.

59% of all papers (industry and academic research) provide toy examples only or do not present an evaluation. Empirical evaluation, industry examples, and industrial applications are each provided by 16% of the papers, followed by exploratory/descriptive validation (7%) and academic applications (0.7%). Five papers present secondary studies such as systematic literature reviews. An analysis of the development of the evaluation type over time reveals, however, that there is less and less academic research with no evaluation (61% 1996-2002; 29% 2003-2007; 17% 2008-2012; 8% 2013-2017) and more and more academic research providing empirical evaluations (from 0% in 1996-2002 to 38% in 2013-2017). This also increased for industry research (from 5% in 1996 to 38% now). This aligns with similar findings in other areas, e.g., software engineering in general [31] and software architecture in particular [10].

In some cases the categorisation with respect to the type of evaluation performed was challenging. For example, some papers call the evaluation "case study" but what is presented is rather an industry or even an artificial example. It was sometimes also difficult to judge whether the example was industrial or artificial but still inspired by industry needs and industry experience of authors.

Key finding(s):

- While both academic and industry research address diverse application domains, academic research is mostly generic, i.e., does not address domain constraints.
- Industry focuses a lot on embedded and software-intensive systems, but a large percentage is also generic.
- The majority of academic research (61%) and also some industry research (11%) is not properly validated (no evaluation or artificial examples only). However, this has improved over time.
- The reporting of the evaluations and/or examples presented in papers is often weak.

3.2 RQ1: Phases, Activities and Topics

Here we explore which SPL engineering phases, SPL development activities and cross-cutting topics have been covered at SPLC and whether there is a difference in phases, activities and topics investigated in academic and industry research.

3.2.1 Product Line Life-Cycle Phases. Domain engineering is by far the most covered phase in research presented at SPLC (64% of reviewed papers). Application engineering – i.e., how to build concrete products within a product line – is covered by 35% of reviewed papers. How to synchronise domain and application engineering is only addressed in 11% of the reviewed papers[4].

[4]Note that the sum of percentages exceeds 100% since a paper could address more than one SPL engineering phase.

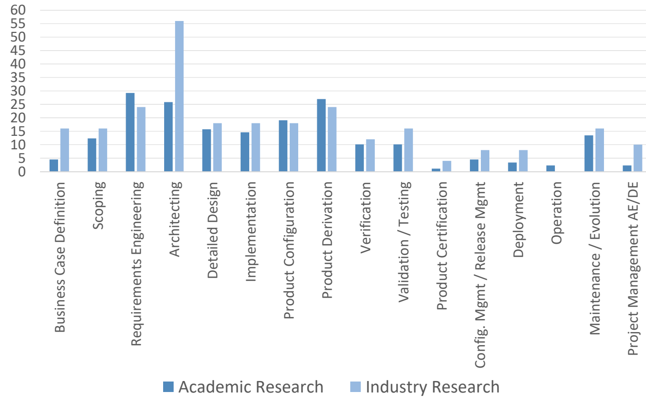

Figure 3: RQ1: Activities addressed in academic vs. industry research (in %; relative to num papers in each category).

When comparing the relative number of papers addressing a certain SPL life-cycle phase in academic research or industry research papers, we found no big difference. For instance, in absolute numbers 56 (i.e., 63% of all 89) academic papers and 32 (i.e., 64% of all 50) industry papers focus on domain engineering.

3.2.2 Product Line Development Activities. Architecting is the dominating product line development activity covered by 38% of reviewed SPLC papers. Other activities, such as configuration and release management (6% of papers), project management (5% of reviewed papers), deployment (5% of papers), product certification (2% of papers) and operation (1% of papers) are less covered. However, in contrast to SPL engineering phases, we noticed a difference between academic research and industry research related to SPL development activities (see also Figure 3):

- Product line architecting is addressed in 28 industry papers and 23 academic papers. While absolute numbers of papers are similar, this means that 56% of all industry papers address architecting, while only 26% of all academic papers address this activity. The most addressed activity in academic papers is requirements engineering (including domain analysis), which is addressed in 29% of all academic papers and 24% of industry papers.
- Product line business case definition is addressed in eight industry papers and four academic papers. Again, this means that 16% of industry papers address this activity, while only 4% of academic papers address it. However, given the low total number, this difference in academic and industry papers may not be significant. A similar imbalance towards industry research can be observed for project management.
- Regarding product line operation, only two academic papers [20, 24] exist where one of these papers is a secondary study on context awareness for dynamic service-oriented product lines and refers to the other paper.

Most other product line development activities are relatively equally addressed in academic as well as industry papers (see Figure 3). A general observation is that SPL research (in academia and industry) appears to focus on activities related to early life-cycle phases and higher-level activities, such as requirements engineering and

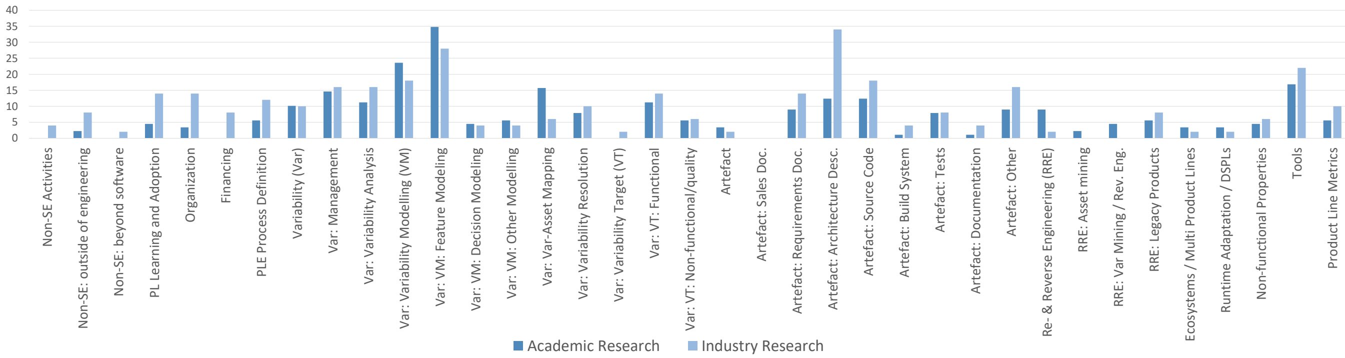

Figure 4: RQ1: Topics addressed in academic vs. industry research (in %; relative to num papers in each category).

architecting, and less on later life-cycle phases (or implementation-related activities) such as testing, deployment, and operation. An exception is maintenance and evolution, which is addressed in 20 papers (twelve academic and eight industry papers, i.e., 13% of academic papers and 16% of industry papers).

3.2.3 Cross-cutting Topics. Through analysing cross-cutting topics we discovered some interesting findings (see also Figure 4):

Variability management and modelling: Of those papers that are about variability modelling, most focus on feature modelling (31% of all papers, 35% of academic papers, and 28% of industry papers). Decision modelling is rather poorly covered (4% of all papers) as are other variability modelling approaches (5%). Variability in quality and quality attributes is a concern in 6% of papers. A big difference between academic and industry papers exists regarding works on mapping variability (and model elements) and product line assets. This topic is covered in 14 academic papers, but only in three industry papers (i.e., 16% of academic papers and 6% of industry papers). On the other hand, variability analysis is relatively covered more in industry papers (ten [i.e., 11% of] academic papers versus eight [i.e., 16% of] industry papers).

Organisational and process-related topics: Topics such as the marketing of SPLs and engineering beyond software are mostly only addressed in industry papers. The same holds for topics such as product line learning and adoption, organisation, and financing. Product line process definition seems to be important in both academic and industry research, but relatively more in industry (five [i.e., 6% of] academic vs. six [i.e., 12% of] industry papers).

Artefacts: When investigating what artefacts are impacted by variability we found that architecture documents (21% of papers) and source code (14%) are the most frequently addressed artefacts, while tests (8%) and sales documents (0%) are least covered. Requirements documentation is covered both in industry and academia, but more in industry (9% of academic papers versus 14% of industry papers). For architecture description artefacts, the difference between academic and industry research is rather large, i.e., 12% covered in academic research compared to 34% in industry research. Source code is also more covered in industry research than in academia (18% vs. 12%). Test artefacts are equally covered (in about 8% of both, academic and industry papers). For industry papers, there is a longer list of other artefacts, than for academia such as tenants in cloud-based or service-oriented systems [33], bills-of-materials [19], or XML documentation [37].

Reverse engineering: This topic is discussed in 17% of all papers, mainly focusing on re-engineering legacy products when adopting a product line approach. Reverse engineering of legacy products is, however, covered slightly more in industry (in 8% of industry papers) compared to academia (in 6% of academic papers).

Non-functional properties, tools and metrics: Non-functional properties are discussed in 5% of all papers (i.e., seven papers), mainly discussing software performance and resource consumption in an SPL context. When differentiating academic and industry papers, four academic (5%) and three industry papers (6%) discuss non-functional properties. Tools to offer practical solutions or (partial) implementations of SPL engineering approaches are provided in 19% of papers. Here, tools include prototypes built for solution approaches in papers or the use of existing tools (e.g., Gears [19]); 17% of all academic papers and 22% of all industry papers discuss a tool. There are many academic prototypes and also few commercial tools (also see [2]). Metrics (e.g., to measure variability, efficiency) appear in 7% of papers. More specific, ten papers (five academic papers [i.e., 6% of all academic papers] and five industry papers [i.e., 10% of all industry papers]) focus on metrics, mostly on (SPL adoption) costs and ROI, but also on test coverage and productivity.

Recent topics: More recent topics such as software ecosystems or multiple product lines and dynamic software product lines are only discussed in 3% of reviewed papers, i.e., in eight papers, only two from industry. The two industry papers are quite old (both are from the year 2000) and focus on product populations in the context of consumer electronics [36] and building software product line architectures for real-time embedded diesel engine controls [9]. This means industry was talking about these topics much earlier than academia.

Key finding(s):

- Domain engineering is the dominating SPL engineering phase investigated in academic and industry research at SPLC. There is only little difference between academic and industry research related to the coverage of SPL phases.
- Architecting is the most considered SPL engineering activity (esp. in industry) followed by requirements engineering.

- Non-software/business-oriented topics are covered more in industry research.
- Overall, there is a clear focus of research in both academia and industry on topics related with variability management and modelling.
- Non-functional properties, like performance or reliability, are no focus of SPL research in both academia and industry.
- Organisational and process-related topics are not studied well and mostly presented as experience reports.
- More recent research topics in academic research such as software ecosystems and multi-product lines, or dynamic SPLs are not covered much in recent industry research.

3.3 RQ2: Evolution of Phases, Activities and Topics

RQ2 explores how the presented phases, activities, and topics evolved over time in academic and industry research and explores whether and how the relationship has changed over time. We have searched for noticeable trends in the data. As different trends in academic and industry research could cancel each other out, we first investigated in all items trends in academic research then trends in industry research and afterwards compared them, if any were identified.

3.3.1 Evolution of Phases. When comparing the relative number of papers addressing a certain product line life-cycle phase in academic and industry research papers, we found that there is no strong trend over time. Also, there is no big difference in the relationship between academic and industry research.

3.3.2 Evolution of Activities. Regarding SPL development activities we could identify several trends (see also Figure 5).

In both academic and industry research, the following activities show a declining trend (i.e., are less and less investigated): business case definition (the declining trend is stronger in academic papers), architecting and detailed design, and product derivation.

Activities with an increasing trend for both academia and industry are: product configuration and validation and testing. While operation is increasingly investigated in academic papers, the industry papers we analyses have not addressed operation.

For several activities, trends of academic research and industry research do not align:

- Scoping shows a slightly increasing trend in academic papers and a slightly decreasing trend in industry papers.
- Requirements engineering shows a slightly increasing trend in academic papers and a stronger decreasing one in industry papers.
- Implementation is slightly less investigated in academic papers, while it is increasingly investigated in industry papers.
- Verification as well as configuration management and release management are increasingly investigated in the last years in academic papers, while the number of industry papers remained similar over time.
- Maintenance and evolution is increasingly investigated in academic papers, while industry papers show a declining trend.

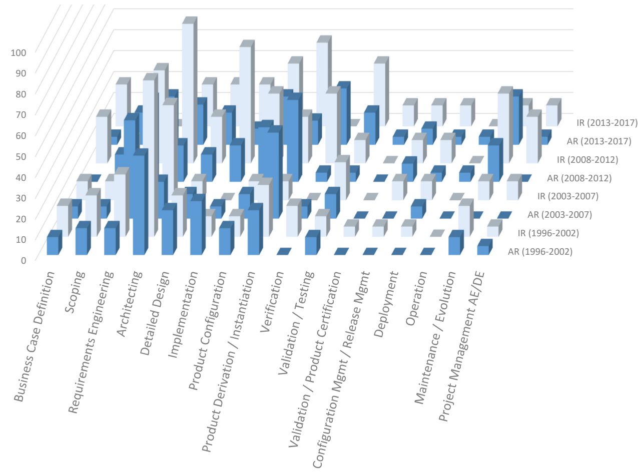

Figure 5: RQ2: Activities addressed in academic research (AR) vs. industry research (IR) over the years (in %; relative to num papers in each category).

3.3.3 Cross-cutting Topics. When analysing cross-cutting topics we have discovered the following trends (see Figure 6):

Organisational and process-related topics: Product line learning and adoption has been addressed in academic papers intensively in the early years and then disappeared, while the topic has been covered in industry papers at a constant level over time. The interest in organisation-related topics is slightly increasing in academic papers, while there is a slightly declining trend in industry papers. Financing shows a declining trend in industry papers, while the activity has not been covered by academic papers at all.

Variability management and modelling: While the number of variability-related publications has increased in academia steadily over time, the number of industry papers was high until 2007 and then dropped in recent years. An interesting evolution can also be found for variability analysis. There is a noticeable increasing trend for academic papers, which has started in 2003. In industry papers, the topic has been addressed in the very early days, then was not investigated much for several years, but increasingly is investigated in recent years again. The strongest overall trend can be found for feature modelling: both academic and industry papers show a strong increasing trend.

Artefacts: When investigating trends around artefacts, we found that requirements documents have been addressed over the years in industry papers at a constant level, while in academia there is a strong increase until 2007 and afterwards a decreasing trend. Remarkably, neither academia nor industry has covered the topic in the recent years. For architecture documents, there is a strong decreasing trend in both academia and industry. While the topic was very strong in the early days, it has almost disappeared in recent years. Another interesting observation can be made for build systems. Both industry and academia have recently started to address this topic. However, we found relatively more publications in industry than in academia on this topic.

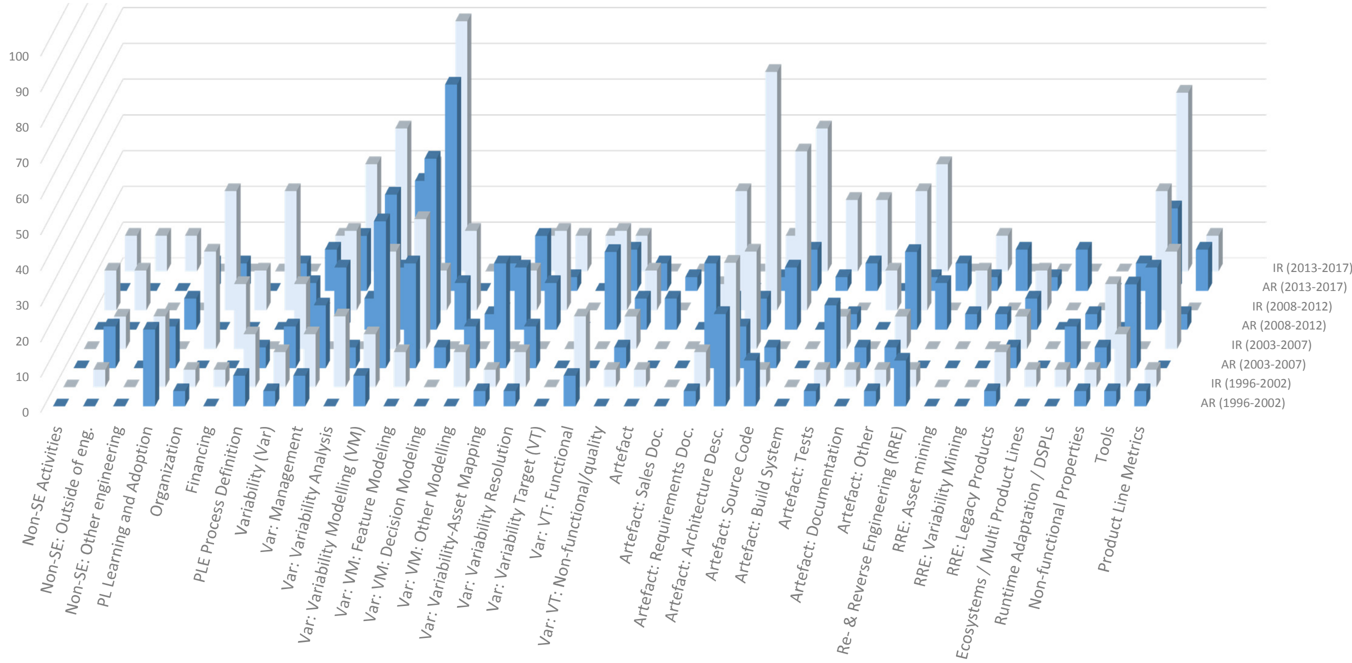

Figure 6: RQ2: Topics addressed in academic research (AR) vs. industry research (IR) over the years (in %; relative to num papers in each category).

Reverse engineering: Mining of variability has attracted increasing interest of academia from 2008 onwards. However, industry papers have not addressed the topic at all over the years. The reverse engineering of legacy products shows a decreasing trend in industry papers, while the level of academic publications remained stable over time, but on a relatively low level.

Tools and metrics: Regarding tools, academic papers show a strong increasing trend over time, while the number of industry papers remained stable in the beginning and has just increased in recent years. For SPL metrics, there is a noticeable peak of industry papers from 2003 to 2007. Before and after that, only few industry papers were found on the topic. However, for academic papers the number remained on a low level over the years and has just increased strongly in recent years.

Key finding(s):
- There is no clear evolution of trends regarding SPL engineering phases.
- Academia and industry less and less investigate architecting and product derivation over the years and both increasingly investigate product configuration and SPL testing.
- Academic research in early years intensively investigated product line adoption but then stopped. Industry research still is looking a lot into how to adopt SPL engineering.
- Requirements engineering, verification, and configuration and release management are increasingly investigated in academia, while industry publications less report about these activities.
- The interest in feature modelling has strongly increased in academia and industry over time.
- There is an increasing interest of academia in variability analysis. Industry has considered the topic in early days and recently came back to it.
- Interest in SPL implementation has increased in industry over time and has decreased in academia.

4 DISCUSSION OF RESULTS

The goal of this paper is to provide evidence to confirm or refute the hypothesis that the work on SPLs in industry and academia is increasingly less aligned and drifting apart. A primary result regarding this hypothesis is:

Hypothesis evaluation:
- The difference between academic and industry SPL research is not that large, after all.

However, as discussed in the previous sections, if we zoom into the details, the picture is not always so clear. Here, we want to summarise those findings and outline some resulting potential for future research. We will also try to provide propositions for the observations, where appropriate. Some of them provide a basis for further research. This can be seen in Figure 3 and 4: while there are differences, the basic distribution of phases, activities and topics in academic and industry papers are mostly very similar. There are only few differences that stand out. For example, regarding activities, architecting is much more strongly represented in industry research than in academic research. This is echoed by the fact that the artefact architecture description is particularly often addressed in industry research. If we look at the development over time, this gap is also widening. This is the case as initially also a large amount of research on software architectures for product lines was published at SPLC by academia, but this reduced drastically after the first few years (cf. Figure 5). This difference could point to a need for more academic research in this area or it could mean that such research is published at other venues (e.g., ICSA, WICSA), or it could mean that the open issues are not substantial enough to warrant novel academic research.

There are also some areas like business case definition, SPL adoption, organisation, and more generally non-SE activities, which are not widely addressed, but nearly exclusively in industrial research. However, this may be partially explained by the fact that, while these areas are relevant to software engineering in practice, they are not typical software engineering topics. Hence, it is not too surprising that they are hardly addressed in academic research. While some fluctuations could be observed over time, there is no clear pattern. On the other hand, this observation may indicate the need for the SPLC community to broaden the perspective towards business- and organisation-oriented expertise.

There are also cases, where the interest in academia is increasing, while they are increasingly less represented in industrial research. Requirements engineering, verification, and release management are examples of this. It is difficult to interpret this, as it is unclear why the interest in industry is becoming less. It could be that other topics are simply regarded as being more pressing or that the current level of technologies is actually regarded as sufficient in industry. It is not possible to distinguish this based on the available data. It might be interesting to analyse this with other means beyond literature studies, such as a survey, also as our own perception differs from the data, i.e., in our experience requirements engineering and configuration management are still hot topics in practice.

Beyond these diverging trends, we can also see cases where the changes over time in industry and research are very similar. The most obvious case is the continuous increase in variability management, variability analysis and, in particular, the use of the feature modelling approach. This can be seen clearly in Figure 6.

SPLC had and continues to have a strong industry focus; 60 papers were written at least with participation (or alone) by industry authors, while 80 papers were written by academics only; this is a 3 to 4 relation, which can be considered very good.

Another aspect that stands out is that while academic research often claims generic applicability (65% of papers), this is hardly the case in industry (20%). However, from the analysis alone it is not clear whether this is due to academics only focusing on generic problems, academics misinterpreting their solutions as generic (even when they are not), or industry researchers, who only state their solutions as domain-relevant even though they may be more widely applicable. This phenomenon may warrant wider analysis, especially from the perspective of context-driven research [6].

The fact that the rigor of evaluations presented in the papers we analysed improved significantly from the early years of the conference until today (with only 8% of academic papers still having no real evaluation) shows the growing maturity of the community. This is essential, not only in light of rigor but also (industrial) relevance of research work [17].

Implications for researchers and practitioners:

- Some software engineering areas of high industrial interest are underrepresented in academic SPL research, this holds in particular for architecture research.
- There are some areas beyond software engineering that are of interest to industry, which are not addressed by academic SPL research. This may be due to a lack of participation of academics from other disciplines.
- In some areas with much academic research and little industrial participation, there is a need to better understand what are the issues in industrial uptake.
- There is a need to better understand the domain-specificity of the research results. This may also help academic researchers to identify relevant constraints and better understand the applicability of their research.

5 THREATS TO VALIDITY

External validity refers to the generalisability of findings to all published research on SPLs and beyond SPLC. The results presented in this paper are based on the analysis of a set of scientific, peer-reviewed publications published at SPLC events from 1996-2017. We did not analyse all SPLC publications and also did not analyse SPL-related publications in other conferences, journals, and books. The validity of data extracted from papers of SPLC events is supported by previous work that states that software engineering conferences use the most common practices of research in a community [31]. Furthermore, incorporating other venues would require an extra step to separate SPL-related research from other research, which could cause additional validity threats. Hence, the set of 140 papers published at the main forum for SPL-related research provides a representative sample and offers a good starting point to investigate the research questions posed in this paper. We aim to extend our study in future work.

Internal validity refers to the extent to which a causal conclusion based on a study is warranted. In this study, it was not always straightforward to identify the type of research performed. This is because the papers presented in the different tracks of the conference programs do not necessarily match with academic versus industry research. A number of events, in particular in the earlier years, had only a single track. The affiliation of the authors is also not an absolute criterion to categorise the type of research. Also, in some cases the categorisation of the type of evaluation performed was challenging. For instance, while some papers claim they report a case study, what is actually often presented is rather an industry or artificial example. To mitigate this risk, the authors defined clear criteria to distinguish between the different research types as well as different evaluation types using two rounds of pilots. During these pilots, two researchers identified the research type and evaluation type of each paper and all seven researchers discussed the overall results to converge to well-defined criteria.

Reliability refers to ensuring that the results obtained from this study are the same if the study would be conducted again. The researchers that extracted the data may have been biased in their decisions to select particular topics. In particular, the study requires a common understanding among all reviewers about the search and analysis methods. Misunderstandings of concepts could potentially cause biased results. To mitigate this threat, seven experienced researchers extracted the data based on a well-defined research protocol, that specified the list of activities and topics, with the data extraction form (that was created based on existing frameworks [35] and our experiences). To establish agreements about the searching criteria, we performed pilots to iteratively refine the criteria ensuring a selection process as unbiased as possible. During the pilot phase, all data was extracted twice for each paper, independently by two researchers, and discussed to reach mutual agreement. After the pilot phase, each researcher extracted data for exactly 15 different papers, but the overall results were discussed among all authors when writing this paper.

6 RELATED WORK

We discuss (i) surveys and reviews on SPL research and (ii) work that focuses on the relation of academia and industry in SE research.

6.1 SPL Surveys and Systematic Reviews

A recent bibliometric analysis of 20 years of SPL research [14] showed that: (i) software architecture was the initial driver of research in SPL (also confirmed in our study). (ii) work on systematic software reuse has been essential for moving the field of SPL forward; and (iii) feature modelling has been the most important topic for the last fifteen years (also confirmed in our study).

Chen and Babar [7] reviewed variability management approaches and showed that the majority of reported approaches have not been sufficiently evaluated using scientifically rigorous methods (see our results on evaluation types). Czarnecki et al. [8] clarified the relation between feature modelling and decision modelling as the two most researched on types of variability modelling approaches.

Galster et al. [11] showed that variability in software systems in general is studied in all engineering phases (our study also showed that variability is a cross-cutting topic widely investigated in academia and industry).

Berger et al. [4] studied the use of variability modelling techniques. The results offer insights into the perceived benefits of variability modelling, the notations and tools used, the scale of industrial models, experienced challenges and mitigation strategies. Similarly, Martinez et al. [21] collected a catalogue of SPL adoption case studies comprehensive information, aiming to foster the advance of the field. Bashroush et al. [2] analysed 37 tools for variability management. The analysis showed that the tools are well motivated, but often lack empirical data to support claims. Qualities regarding the practical use of tools such as usability, integration, and scalability were not studied for most tools.

While existing studies have investigated various aspects of SPL in detail, none of the existing studies has focused on assessing (the evolution of) SPL research in academia and industry over time.

6.2 Academia and Industry

Ivanov et al. [16] surveyed software engineers about what they care about when developing software and compared the results with the research topics of the papers published at ICSE and FSE recently. Briand et al. [6] argued for context-driven software engineering research to increase its impact and be more successful, i.e., research should focus on problems defined in collaboration with industrial partners and driven by concrete needs in specific domains and development projects. Wohlin et al. [39] identified key factors for collaboration between industry and academia such as buy-in and support from company management, having a champion at the company, mutual understanding of role and skills of people, and social skills. Garousi et al. [12] conducted a systematic literature review to identify challenges and best practices of industry-academia collaboration. They confirm the factors Wohlin et al. [39] had presented in 2012.

While these studies look at gaps between research and practice in software engineering in general, this paper focuses on the field of SPLs. Our results provide empirically-grounded input for further discussions and reflections within the community.

7 CONCLUSIONS

We have presented a study comparing industry and academic SPL research by analysing 140 papers published at SPLC events from 1996-2017. While this is a (randomised) selection of about a fourth of the published papers, we think that already significant insights can be drawn from this.

It was to our surprise that we could not identify fundamental differences and gaps between academic and industry research. While the topic distributions do not precisely match between academic and industry research, given the significant variation among the years, there are only few differences that stand out as discussed in Section 4. However, these differences have not significantly increased over time. Thus, we can conclude that SPL research both from an academic and an industry perspective seem to be mostly in line with each other, even though the details of the distribution differ. This finding seems very important as it implies that cooperation and communication in the community overall work well, even though some local and temporary deviations may occur.

We aim in our future work to analyse more SPLC publications, analyse other SPL-related publications (from other conferences, journals, books, tech. reports), discuss our results with peers (get feedback from actual authors of analysed publications), and also want to conduct a survey with academics and industry people on their perception of relevant phases, activities, and topics. Particularly, we aim to analyse and discuss the impact of research work from academia in industry and vice versa. We also plan to further refine our research process, e.g., explore other ways of classifying papers and extracting additional information.

ACKNOWLEDGMENTS

This work was supported, in part, by the Christian Doppler Forschungsgesellschaft, Austria and Primetals Technologies (Rabiser), by the ITEA3 project REVaMP2, funded by the BMBF (German Ministry of Research and Education) under grant 01IS16042H (Schmid), and by Science Foundation Ireland grant 13/RC/2094 (Botterweck). Any opinions expressed herein are solely by the authors and not by the supporting agencies.

REFERENCES

[1] Mathieu Acher, Roberto E. Lopez-Herrejon, and Rick Rabiser. 2017. Teaching Software Product Lines: A Snapshot of Current Practices and Challenges. *TOCE* 18, 1 (2017), 2:1–2:31.

[2] Rabih Bashroush, Muhammad Garba, Rick Rabiser, Iris Groher, and Goetz Botterweck. 2017. CASE Tool Support for Variability Management in Software Product Lines. *ACM Comput. Surv.* 50, 1 (2017), 14:1–14:45.

[3] Joachim Bayer, Oliver Flege, Peter Knauber, Roland Laqua, Dirk Muthig, Klaus Schmid, Tanya Widen, and Jean-Marc DeBaud. 1999. PuLSE: A Methodology to Develop Software Product Lines. In *Proc. Symp. Softw. Reusability*. ACM, 122–131.

[4] Thorsten Berger, Ralf Rublack, Divya Nair, Joanne M. Atlee, Martin Becker, Krzysztof Czarnecki, and Andrzej Wąsowski. 2013. A survey of variability modeling in industrial practice. In *Proc. 7th Int'l Workshop on Variability Modelling of Software-intensive Systems*. ACM, 7:1–7:8.

[5] Stefan Biffl, Marcos Kalinowski, Rick Rabiser, Fajar J. Ekaputra, and Dietmar Winkler. 2014. Systematic Knowledge Engineering: Building Bodies of Knowledge from Published Research. *International Journal of Software Engineering and Knowledge Engineering* 24, 10 (2014), 1533–1572.

[6] Lionel C. Briand, Domenico Bianculli, Shiva Nejati, Fabrizio Pastore, and Mehrdad Sabetzadeh. 2017. The Case for Context-Driven Software Engineering Research: Generalizability Is Overrated. *IEEE Software* 34, 5 (2017), 72–75.

[7] Lianping Chen and Muhammad Ali Babar. 2011. A systematic review of evaluation of variability management approaches in software product lines. *Information & Software Technology* 53, 4 (2011), 344–362.

[8] Krzysztof Czarnecki, Paul Grünbacher, Rick Rabiser, Klaus Schmid, and Andrzej Wąsowski. 2012. Cool features and tough decisions: a comparison of variability modeling approaches. In *Proc. 6th Int'l Workshop on Variability Modelling of Software-Intensive Systems*. ACM, 173–182.

[9] James C Dager. 2000. Cummins's experience in developing a software product line architecture for real-time embedded diesel engine controls. In *Software Product Line Conf.* Springer, 23–45.

[10] Matthias Galster and Danny Weyns. 2016. Empirical Research in Software Architecture: How Far Have We Come?. In *Proc. 13th Working IEEE/IFIP Conf. on Software Architecture*. IEEE, 11–20.

[11] Matthias Galster, Danny Weyns, Dan Tofan, Bartosz Michalik, and Paris Avgeriou. 2014. Variability in Software Systems - A Systematic Literature Review. *IEEE Trans. Software Eng.* 40, 3 (2014), 282–306.

[12] Vahid Garousi, Kai Petersen, and Baris Ozkan. 2016. Challenges and best practices in industry-academia collaborations in software engineering: A systematic literature review. *Information and Software Technology* 79 (2016), 106–127.

[13] Herman Hartmann, Tim Trew, and Aart Matsinger. 2009. Supplier Independent Feature Modelling. In *Proc. 13th Int'l Software Product Line Conf.* ACM ICPS, 191–200.

[14] Ruben Heradio, Hector Perez-Morago, David Fernández-Amorós, Francisco Javier Cabrerizo, and Enrique Herrera-Viedma. 2016. A bibliometric analysis of 20 years of research on software product lines. *Information & Software Technology* 72 (2016), 1–15.

[15] Gerald Holl, Paul Grünbacher, and Rick Rabiser. 2012. A systematic review and an expert survey on capabilities supporting multi product lines. *Information & Software Technology* 54, 8 (2012), 828–852.

[16] Vladimir Ivanov, Alan Rogers, Giancarlo Succi, Jooyong Yi, and Vasilii Zorin. 2017. What do software engineers care about? gaps between research and practice. In *Proc. 11th Joint Meeting on Foundations of Software Engineering, ESEC/FSE*. ACM, 890–895.

[17] Martin Ivarsson and Tony Gorschek. 2011. A method for evaluating rigor and industrial relevance of technology evaluations. *Empirical Software Engineering* 16, 3 (2011), 365–395.

[18] Anssi Karhinen, Alexander Ran, and Tapio Tallgren. 1996. Configurable Designs. In *Proc. Int'l Workshop on Development and Evolution of Software Architectures for Product Families, Madrid*.

[19] Charles W Krueger. 2015. Mechanical product lifecycle management meets product line engineering. In *Proc. 19th Int'l Software Product Line Conf.* ACM, 316–320.

[20] C Marimuthu and K Chandrasekaran. 2017. Systematic Studies in Software Product Lines: A Tertiary Study. In *Proc. 21st Int'l Systems and Software Product Line Conf.* ACM, 143–152.

[21] Jabier Martinez, Wesley K. G. Assunção, and Tewfik Ziadi. 2017. ESPLA: A Catalog of Extractive SPL Adoption Case Studies. In *Proc. 21st Int'l Systems and Software Product Line Conf.* ACM, 38–41.

[22] Linda M. Northrop. 2002. SEI's Software Product Line Tenets. *IEEE Software* 19, 4 (2002), 32–40.

[23] David Lorge Parnas. 1976. On the Design and Development of Program Families. *IEEE Trans. Software Eng.* 2, 1 (1976), 1–9.

[24] Carlos Parra, Xavier Blanc, and Laurence Duchien. 2009. Context awareness for dynamic service-oriented product lines. In *Proc. 13th Int'l Software Product Line Conf.* ACM ICPS, 131–140.

[25] Kai Petersen, Sairam Vakkalanka, and Ludwik Kuzniarz. 2015. Guidelines for conducting systematic mapping studies in software engineering: An update. *Information and Software Technology* 64 (2015), 1–18.

[26] Rick Rabiser, Martin Becker, Goetz Botterweck, Matthias Galster, Iris Groher, Klaus Schmid, and Danny Weyns. 2018. Our Study Material. (2018). https://tinyurl.com/SPLAcadVsInd

[27] Rick Rabiser, Paul Grünbacher, and Deepak Dhungana. 2010. Requirements for product derivation support: Results from a systematic literature review and an expert survey. *Information & Software Technology* 52, 3 (2010), 324–346.

[28] Ina Schaefer, Rick Rabiser, Dave Clarke, Lorenzo Bettini, David Benavides, Goetz Botterweck, Animesh Pathak, Salvador Trujillo, and Karina Villela. 2012. Software diversity: state of the art and perspectives. *STTT* 14, 5 (2012), 477–495.

[29] Klaus Schmid and Tanya Widen. 2000. Customizing the PuLSE^{TM} Product Line Approach to the Demands of an Organization. In *Proc. 7th European Workshop on Software Process Technology*. Springer, 221–238.

[30] Pierre-Yves Schobbens, Patrick Heymans, and Jean-Christophe Trigaux. 2006. Feature Diagrams: A Survey and a Formal Semantics. In *Proc. 14th IEEE Int'l Conf. on Requirements Engineering*. IEEE, 136–145.

[31] Janet Siegmund, Norbert Siegmund, and Sven Apel. 2015. Views on Internal and External Validity in Empirical Software Engineering. In *Proc. 37th Int'l Conf. on Software Engineering*. IEEE, 9–19.

[32] Douglas Stuart, Wonhee Sull, Steve Pruitt, Deborah Cobb, Fred Waskiewicz, and T. W. Cook. 2000. The SSEP Toolset for Product Line Development. In *Software Product Lines: Experience and Research Directions*. Springer US, 413–435.

[33] Leonardo P Tizzei, Marcelo Nery, Vinícius CVB Segura, and Renato FG Cerqueira. 2017. Using Microservices and Software Product Line Engineering to Support Reuse of Evolving Multi-tenant SaaS. In *Proc. 21st Int'l Systems and Software Product Line Conf.* ACM, 205–214.

[34] Frank van der Linden. 2002. Software Product Families in Europe: The Esaps & Café Projects. *IEEE Software* 19, 4 (2002), 41–49.

[35] Frank van der Linden, Klaus Schmid, and Eelco Rommes. 2007. *Software product lines in action - the best industrial practice in product line engineering*. Springer.

[36] Rob van Ommering. 2000. Beyond product families: Building a product population?. In *Int'l Workshop on Software Architectures for Product Families*. Springer, 187–198.

[37] Rob van Ommering. 2001. Roadmapping a product population architecture. In *Proc. Int'l Workshop on Software Product-Family Engineering*. Springer, 51–63.

[38] Roel Wieringa, Neil A. M. Maiden, Nancy R. Mead, and Colette Rolland. 2006. Requirements engineering paper classification and evaluation criteria: a proposal and a discussion. *Requir. Eng.* 11, 1 (2006), 102–107.

[39] Claes Wohlin, Aybüke Aurum, Lefteris Angelis, Laura Phillips, Yvonne Dittrich, Tony Gorschek, Håkan Grahn, Kennet Henningsson, Simon Kågström, Graham Low, Per Rovegard, Piotr Tomaszewski, Christine Van Toorn, and Jeff Winter. 2012. The Success Factors Powering Industry-Academia Collaboration. *IEEE Software* 29, 2 (2012), 67–73.