Global Software Engineering: Evolution and Trends

Christof Ebert
Vector Consulting Services
Stuttgart, Germany
Christof.Ebert@vector.com

Marco Kuhrmann
University of Southern Denmark
Mærsk Mc-Kinney Møller Institute
Odense, Denmark
kuhrmann@mmmi.sdu.dk

Rafael Prikladnicki
Pontifícia Universidade Católica
do Rio Grande do Sul (PUCRS)
Porto Alegre, Brazil
rafaelp@pucrs.br

***Abstract*—Professional software products and IT systems and services today are developed mostly by globally distributed teams, projects, and companies. Successfully orchestrating Global Software Engineering (GSE) has become the major success factor both for organizations and practitioners. Yet, more than a half of all distributed projects does not achieve the intended objectives and is canceled. This paper summarizes experiences from academia and industry in a way to facilitate knowledge and technology transfer. It is based on an evaluation of 10 years of research, and industry collaboration and experience reported at the IEEE International Conference on Software Engineering (ICGSE) series. The outcomes of our analysis show GSE as a field highly attached to industry and, thus, a considerable share of ICGSE papers address the transfer of Software Engineering concepts and solutions to the global stage. We found collaboration and teams, processes and organization, sourcing and supplier management, and success factors to be the topics gaining the most interest of researchers and practitioners. Beyond the analysis of the past conferences, we also look at current trends in GSE to motivate further research and industrial collaboration.**

***Index Terms*—global software engineering; GSE; near-shoring; outsourcing; offshoring; longitudinal study; ICGSE**

I. Introduction

Today, hardly any software product or IT service is developed at only one place or by only one team. Software like all industry products is the result of complex multinational supply chains that include many partners from conceptualization over development and production to maintenance. Successfully managing global software projects has rapidly become key across industries. However, a considerable share of those global projects does not meet the expectations [1], [2]. Traditional labor-cost-based location decisions are replaced by systematic improvements of business processes in a distributed context. As we captured at the recent *IEEE International Conference on Software Engineering* (ICGSE; [3]), benefits are tangible: better multi-site collaboration, clear supplier agreements, and transparent interfaces are the most often reported benefits.

In the past decade, Global Software Engineering (GSE), IT outsourcing, and business process outsourcing have shown growth rates of 10-20% per annum [1], [2], [4]. The share of offshoring or globalization depends on the underlying business needs and on what software is being developed. For instance, while distributed development of IT applications is fairly easy, embedded software and system development still faces major challenges when adopting distributed development. An industry panel at recent ICGSE showed that only 30% of all embedded software is developed in a global or distributed context, while the majority is still developed in co-located setups [2]. Similarly, the amount of quality deficiencies and callbacks across industries has increased in parallel to growing global development and sourcing.

This paper provides an overview and longitudinal research of all ICGSE conference instances since the start of this conference series in 2006. It looks back at the topics addressed and their evolution over time, but also studies the knowledge transfer from Software Engineering research towards industrial practice. We analyzed all published conference papers of the ICGSE conference series covering 10 years of research and industry collaboration thus digesting best practices and industry state-of-the-practice in GSE and distributed projects to answer the following research questions:

RQ 1	What are the main fields of interest reported in the ICGSE conference series and how did these themes evolve over time?
RQ 2	What maturity and impact do the themes addressed by the ICGSE publications have?
RQ 3	What trends can be found in the ICGSE conference series and industrial experience to shape future GSE research?

The present paper summarizes experiences from academia and industry to facilitate knowledge and technology transfer. An outlook shows current trends in GSE to lay the foundation for research as well as practical guidance for industry, as distilled from many best practices.

The remainder of the paper is structured as follows: Section II describes the study design for analyzing the ICGSE publications. In Sect. III, we provide the results of analyzing the papers published in 10 years of ICGSE and answer the aforementioned research questions. In Sect. IV, we provide both, a discussion of GSE's state-of-the-practice in industry in combination with further studies related to the present paper. We conclude the paper in Sect. V.

II. Study Design

To carry out the research presented in the paper at hand, we utilized the *systematic review* instrument as described by Kitchenham and Charters [5] and the *systematic mapping study* instrument as described by Petersen et al. [6]. Due

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TABLE I
RESEARCH TYPE FACET ACCORDING TO WIERINGA ET AL. [7].

Category	Description
Opinion	personal opinion whether a certain technique is good or bad, or how things should be done, not grounded in related work and research methodology
Solution	solution for a problem is proposed (or a significant extension), application is demonstrated by example or student labs; also includes proposals complemented by (only) one case study for which no long-term evaluation plan is obvious; demonstration is possible by argumentation; note: this category also includes "validation papers" (mainly example- or lab-based work)
Philosophical	new way of looking/thinking, structuring a field in form of a taxonomy or a framework, secondary studies like SLR or SMS; note: "new way of…" includes transfer research, i.e., approaches/practices used in one domain that are applied and evaluated to another one
Evaluation	implemented in practice (implementation), evaluation of implementation conducted (implementation evaluation); requires more than just one demonstrating case study
Experience	(personal) experience, how are things done in practice; can be either the very personal experience of an author or an industrial experience report

to the nature of the presented study, we deviate in the data collection procedures and study selection procedures: As data source, we used the ICGSE conference proceedings, which are available from the IEEE Digital Library[1]. In total, the ICGSE proceedings comprise 260 papers, which are full-, short-, industry-, and education-related papers. Note, we opted for conference "main track" papers only, i.e., PhD symposium papers, as well as posters and tutorial- or workshop papers were not included for analysis. Eventually, all papers were downloaded and metadata were collected in a spreadsheet for further analysis. In the following, we provide details about the data analysis procedures.

A. Schema Development

As a first step, we selected the schemas to be utilized in the analysis. We opted for a mixed approach in which we rely on (quasi-)standard schemas and also on dynamic schemas crafted from the set of publications analyzed.

As (quasi-)standard schemas, we selected the *research type facet* (RTF) as described by Wieringa et al. [7], the *contribution type facet* (CTF) as for instance used by Petersen et al. [6], and, eventually, we selected the *rigor-relevance model* as proposed by Ivarsson and Gorschek [8] to get an impression about the quality and relevance of ICGSE research. The Tables I, II, and III provide a brief summary of the respective criteria and/or scores.

Beyond these (quasi-)standard criteria and in order to get more insight into the ICGSE publications, we also developed two study-specific schemas. Using a Word Cloud as instrument, we conducted a cluster analysis to work out *themes*, i.e., lists of topics addressed by the published papers. Figure 1 shows the Word Cloud used to derive the themes[2].

[1]All ICGSE conference proceedings are available from http://ieeexplore.ieee.org/servlet/opac?punumber=1001266.

TABLE II
CONTRIBUTION TYPE FACET AS USED BY PETERSEN ET AL. [6].

Category	Description
Theory	construct of cause-effect relationships
Model	representation of observed reality by concepts after conceptualization
Framework	frameworks/methods related to GSD, for instance maturity or organization models that include meta-models, models, and methods to apply them
Guideline	list of advices, recommended best practices/success factors if grounded in empirical evidence
Lessons Learned	set of outcomes from obtained results, for instance findings obtained from (comparative) case studies
Advice	recommendation (usually from opinion without empirical justification)
Tool	a tool (focus: tool), if there is a tool as one building block of a more comprehensive method/framework only, then "framework" is to be chosen

TABLE III
RIGOR-RELEVANCE MODEL ACCORDING TO IVARSSON, GORSCHEK [8].

Category	Description
Rigor (scores: description is strong: 1, medium: 0.5, weak: 0)	
Context described	context of the study
Study design described	reproducible study design incl., e.g., variables, measures, etc.
Validity discussed	threats to validity are classified and discussed
Relevance (scores: contributes to relevance; yes: 1, no: 0)	
Subjects	subjects used are representative
Context	actual context is representative
Scale	research is of "realistic" size
Research method	research methods supports investigation in a realistic setup, i.e., "real" situations

Fig. 1. Top thirty topics addressed in one decade of ICGSE.

Eventually, we found 15 clusters (see Table V) that we used to categorize the papers by their contributions. Note that one

[2]**Note:** In the cluster analysis, we removed words without added value, such as GSE, GSD, global, software, engineering, development. We also replaced plural words with the singular forms when both occurred in the top thirty list.

TABLE IV
MATURITY INDEX TO ASSESS STRENGTH OF EVIDENCE AND INDUSTRY COLLABORATION PATTERN.

Score	Description
Strength of Evidence (scores: NA/NR=0,...,3)	
NA/NR	not relevant (e.g., position paper) or based on experience only, e.g., "success stories" without empirical evidence
Weak	university lab with students only/experiment or simulation
Average	industry is involved, but only 1 case, such as a demonstrator, or secondary studies, due to inherent publication bias
Strong	multi-case, longitudinal or replication studies (can be lab-only or with industry involvement)
Industry Collaboration Pattern (scores: NA=0,...,3)	
NA	no involvement, e.g., university lab only or SLR/SMS
Interview	practitioner interviews only
SingleCase	single case (with/without complementing interviews)
Close	e.g., multiple studies in 1 company, or multiple companies in 1 study, or different research methods applied (mixed-method)

paper can address one or more themes, which we also use to study relationships among different topics.

The second study-specific schema is a maturity index, which consists of two components (Table IV): the first component is the *strength of evidence* to work out how the research (part) was conducted, e.g., are results reported by a paper coming from a "one-shot" student lab or a long-term industry-hosted investigation. The second component is the *industry collaboration pattern* to work out how industry is involved in research. This model has some similarities to the aforementioned rigor-relevance model, but has a slightly different focus, as this model also allows research to be of high relevance, even though industry is not involved in the research (e.g., ground-breaking rigorously researched theories). Finally, both components were used to compute the two "maturity indexes" per theme (*th*):

$$\mathrm{idx}_{\mathrm{th}} = \frac{\sum\limits_{\forall \mathrm{cat}} \left(\mathrm{totalpapers}_{\mathrm{cat}} \times w_{\mathrm{cat}} \times \frac{y_{\mathrm{pub}}}{10} \right)}{\sum \mathrm{totalpapers}_{\mathrm{th}}} \qquad (1)$$

with *cat* denoting the different scores of either the strength of evidence or industry collaboration pattern. For instance, if we compute the index for the *industry collaboration pattern*, we select $cat = \{\mathrm{NA}, \mathrm{Interview}, \mathrm{SingleCase}, \mathrm{Close}\}$ and w_{cat} assigns the weights for the categories with $w_{\mathrm{NA}} = 0.1$, $w_{\mathrm{Interview}} = 0.25$, $w_{\mathrm{SingleCase}} = 0.5$, and $w_{\mathrm{Close}} = 1.0$. To rate the relevance of a theme, y_{pub} denotes the number of years in which papers on a theme were found in the ICGSE proceedings from the past 10 years, i.e., we expect highly relevant themes having a more frequent publication rate.

The index results in a number, and we consider a theme the more "strong" or relevant for bigger numbers. After initial test runs, we set the following threshold: a theme is considered well-researched and highly relevant for industry collaboration

	Communication, Soft Skills	Project Management	Agile	Collaboration and Teams	Architecture and Design	Requirements Engineering	Testing	Knowledge Management	Processes and Organization	Tools and IT Infrastructures	Sourcing and Supplier Management	Quality	Culture	Education and Training	Success Factors
All	38	80	41	69	6	12	11	11	56	43	41	19	28	22	41
2006	10	13	3	16	0	2	5	0	7	8	5	2	6	1	2
2007	4	10	1	13	1	3	0	5	8	3	8	3	2	2	5
2008	4	7	4	8	1	1	1	0	4	4	5	0	0	4	5
2009	5	6	4	7	2	0	0	2	2	4	6	3	10	3	4
2010	4	9	2	3	1	1	0	0	3	8	3	0	2	3	4
2011	4	3	6	3	0	2	1	1	6	0	2	2	2	3	3
2012	3	14	6	4	1	0	2	1	10	6	2	1	1	1	6
2013	2	9	6	6	0	1	2	0	6	5	4	3	3	1	7
2014	1	8	4	4	0	2	0	1	6	3	4	4	1	2	3
2015	1	1	5	5	0	0	0	1	4	2	2	1	1	2	2

Fig. 2. Number of published papers (main conference) per ICGSE instance, and addressed topics by year (and in total).

if the respective index is ≥ 0.4. The results of this evaluation is summarized in Table V.

B. Data Analysis

Data analysis was conducted on the papers' full text. For every paper, the paper was downloaded, the metadata (title, abstract, etc.) was collected, and the classification schemas were iteratively applied. When all the data was available, Microsoft Excel was used to generate descriptive statistics and to perform computations, e.g., for the rigor-relevance model or the maturity indexes. The data obtained from the classification and the computations was then compared to the information gathered from the simple headcount as used in [9] to confirm initially found trends.

C. Validity Procedures

To improve the validity of our findings, as a first measure, we relied on (quasi-)standardized classification schemas to follow a well-accepted and proven approach. To complement these standard schemas with study-specific schemas, we used an iterative and tool-based approach to craft these schemas. All analysis and classification steps were carried out iteratively with continuous quality assurance. Finally, as we rely on a specific pre-defined dataset, we addressed a potential reviewer bias by avoiding a manual paper selection.

III. ANALYZING 10 YEARS OF ICGSE EXPERIENCE

For more than a decade, ICGSE aims at bringing together researchers and practitioners to discuss GSE-related problems and solutions. We therefore analyzed the 260 published conference papers for the topics of interest and for the contributions made over time. In this section, we start by giving an overview of the different themes addressed by the analyzed papers over

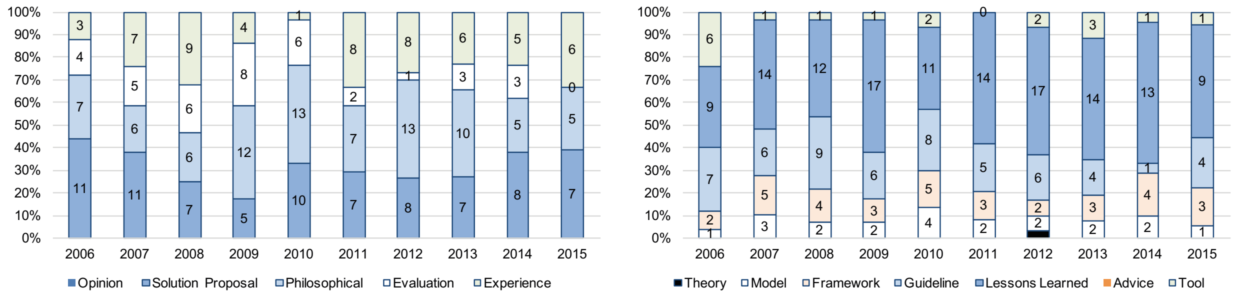

Fig. 3. Overview of the research type facets (left) and the contribution type facets (right) over time.

time. In Sect. III-A and in Sect. III-B, we provide a first trend analysis by inspecting the field's development using the standard classification schemas. In Sect. III-C, we analyze the impact ICGSE research had over time and work out those themes that gained much attention/are perceived of special relevance/importance to the community. The following section contains both, the presentation of the data and a brief in-place discussion/interpretation where applicable.

A. *ICGSE Themes*

Figure 2 illustrates the themes addressed by the ICGSE publications over time. We used a heat-map-like visualization to color-code the frequency of mentions and to identify the champions among the themes.

The illustration shows the topics *Project Management*, *Collaboration and Teams*, and *Process and Organization* of particular interest. In fact, having a more detailed look into the respective papers, we find the general management topics most frequently researched, e.g., project governance, risk management, estimation, collaborative work in teams (incl. task allocation), organization capability improvement, and process transition.

While "normal" Software Engineering challenges have been discussed for years, ICGSE adds distribution as extra dimension thus calling for investigating problems and respectively proposed solutions in a global context. For example, agile and lean practices, which are considered the most promising approaches to improve software development speed and quality are increasingly discussed; closely related to questions of collaboration and team organization, as agile principles, such as on-site customer, direct communication, or shared code ownership have to be adopted to GSE. In the pool of the ICGSE papers we hence found several papers investigating the options to successfully enact agile approaches in GSE; quite often supported by tools, such as Instant Messaging, different collaboration tools, or collaborative testing and debugging. Another aspect—especially in agile software development—is *trust*. We found 16 papers (e.g., [10]–[12]) making trust as a key theme a first-class citizen of the discussion as part of team-, culture-, and sourcing-related contributions.

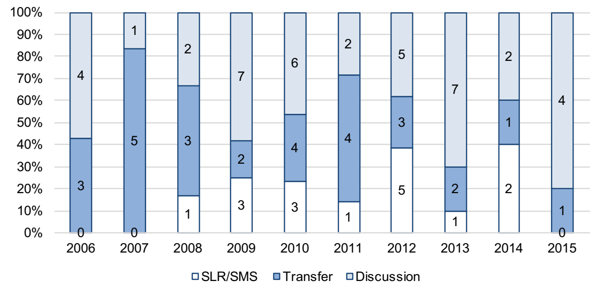

Fig. 4. Overview and refinement of philosophical papers over time.

B. *Development of the Field over Time*

While Fig. 2 gives an initial overview of the themes addressed and their frequency over time, we use the different classification schemas to carry out a more in-depth analysis of the field's development over time.

In Fig. 3, we provide a summary of the CTFs/RTFs addressed by the ICGSE papers over time. The CTF part underlines the aforementioned finding that ICGSE to a large extent fosters knowledge transfer from "classic" SE to GSE. The chart shows the majority of the papers being classified as *guidelines* and *lessons learned*. The RTF part allows for rating the general maturity of the research field. The figure shows two relatively stable trends over time: first, from the very beginning on, ICGSE papers provide evidence based on *evaluation* research and *experiences*. Second, ICGSE has a stable share of papers that are classified as *philosophical papers*, which, among other things, aim to discuss and/or compare given/new concepts from different angles.

In order to better analyze these papers, we introduced three sub-categories, namely *SLR/SMS* to collect all secondary studies, *Transfer* to select those studies that transfer a known concept from SE to GSE, and *Discussion* to select those papers discussing (G)SE problems and to offer/rate different solution approaches. Figure 4 shows that secondary studies, which mostly address aggregating and structuring reported knowledge, account for 19% of the philosophical papers, i.e.,

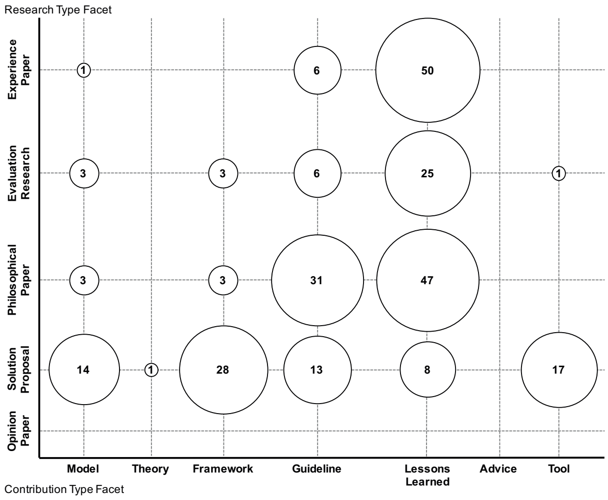

Fig. 5. Systematic map of the research- and contribution type facets.

the majority addresses the knowledge transfer and discussion of solutions. This, again, underlines the significant work the ICGSE community performs to transfer, apply, and analyze SE concepts in the GSE context.

Regarding the maturity of the different contributions published at ICGSE, Fig. 5 provides a systematic map illustrating the achieved research maturity of the particular papers. The map shows again the strong focus on collecting lessons learned and providing guidance. In particular, lessons learned (130 papers, 50%) are the largest share in the result set, and furthermore experience-based lessons learned account for the largest category of papers in the whole result set (50 papers, 19.2%). Hence, the map shows a fairly mature field in terms of guidelines and experiences. However, on the other hand, the map also shows missing theories on GSE (a trend that is quite common to Software Engineering and its sub-disciplines in general), but also some effort in developing models (e.g., to better predict risk, quality, impact of team/distribution pattern, and so forth). Finally, the map shows that individual advice (not grounded in hard evidence) is not present at all, and the map shows that the community is also proposing different tools that help improving collaboration and communication in distributed projects.

The previously presented charts indicate a certain development over time, which is also reflecting the evolving industry needs enforced by changing markets and technologies. The set of analyzed papers contains a number of examples illustrating this evolution. For instance, the ICGSE paper pool comprises different models synthesized from different literature, research, and practitioner-related sources. For example, a Global Teaming Model [13]–[15] provides a structured best-practice-based guideline to set up and run distributed projects, or a Survivability Model [16], [17] that helps analyzing and improving different actions taken in GSE projects. Both exemplarily selected models emerge from long-term research and collaboration, as indicated by the references. Furthermore, different secondary studies (systematic literature reviews and mapping studies) aim to structure the GSE domain with the purpose to structure the current state-of-the-practice and to derive different success factors and guidelines supporting effective GSE project set up and operation, such as [18]–[21]. Finally, the ICGSE papers are to a large extend grounded in applied research in which many companies are involved in GSE (e.g., Siemens, Alcatel, Ericsson, Microsoft, and also many small and medium enterprises, such as [22]–[25]).

C. Relevant ICGSE Themes and their Impact

As just found the previous section, the research quality of the ICGSE papers is mainly driven by evidence-based research, and the evidence presented is, to a large extend, collected in academia-industry collaboration. To inspect this trend suggested by the systematic map in Fig. 5, we applied our custom schema. Figure 6 illustrates the *strength of evidence* and the *industry collaboration pattern* over time. The figure shows (and thereby confirms the interpretation of Fig. 5) the large share of research categorized as *average-strong*. At the same time, the figure shows the high share of close industry collaboration.

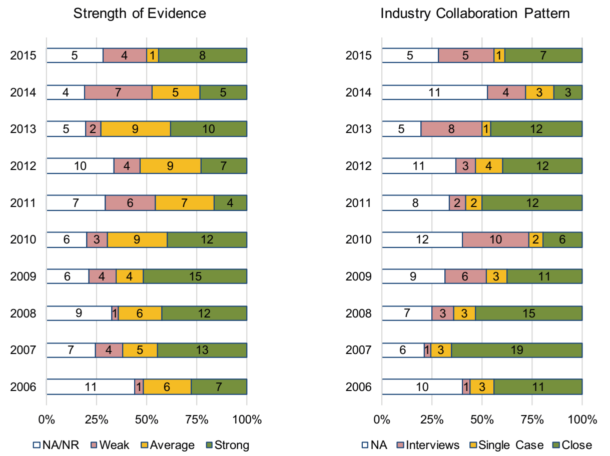

Fig. 6. Overview of the strength of evidence and the industry collaboration pattern over time.

To better (reliably) rate the impact of the research published at ICGSE, we applied two models. The aforementioned model addressing strength of evidence and industry collaboration pattern is complemented by the rigor-relevance model. For both models, in Fig. 7 and Fig. 8, we use the same visualization to investigate the relevance of ICGSE research for industry.

The figures show that, according to the rigor-relevance model (Fig. 7), 74 ICGSE papers are considered highly relevant, and of those, 29 also meet highest requirements regarding the scientific rigor. Although the applied criteria differ, the study specific model in Fig. 8 shows similar trends: 108 papers

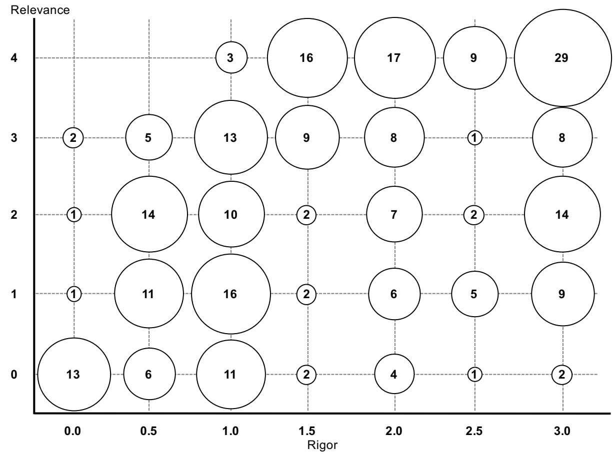

Fig. 7. Rating of the ICGSE papers according to the rigor-relevance model according to [8].

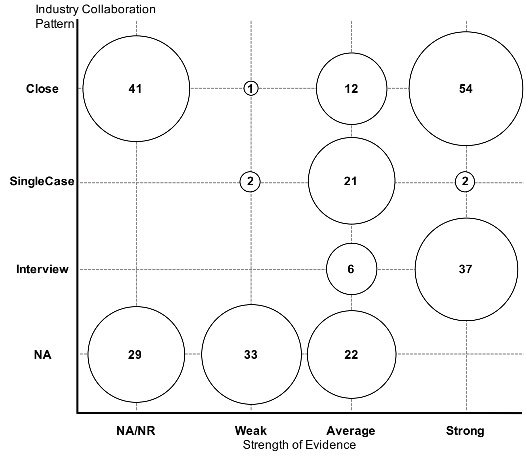

Fig. 8. Evaluation of the ICGSE papers regarding their strength of evidence and industry collaboration pattern.

emerge from a close industry collaboration, and of those, 54 provide strong evidence. This analysis shows the relevance of the ICGSE papers and and their solid foundation in evidence.

Based on the classifications and on the ratings regarding strength of evidence and industry collaboration pattern, we revisited themes with purpose to identify those themes that have a mature research and those with close industry collaboration to eventually conclude the most relevant GSE topics. The results shown in Table V provide two insights: first, the table outlines the mature and relevant themes, and second, the table also shows those topics that are, from the GSE perspective, "under-researched" thus showing routes for future research[3].

In particular, from the research perspective, communication and soft skills, project management, agile, collaboration and teams, process and organization, sourcing and supplier management, quality, and success factors are well researched. From the perspective of the industry relevance, agile, collaboration, process, sourcing, quality, and success factors are researched in close collaboration. That is, collaboration, process, sourcing, and success factors have to be considered the major themes in ICGSE (with highest research maturity and biggest impact to industry).

Compared to Fig. 2, this rating draws a slightly different picture. From the simple headcount, project management was the champion. However, Table V states project management a well-research topic with yet little industry involvement. The same holds for the topic agile, which is present in the result set with strong industry involvement, yet lacking strong evidence. Another finding, which just became obvious in Fig. 2, is the low number of papers addressing testing. Actually, testing was perceived as one of the core software development activities suitable for outsourcing. However, the numbers obtained from analyzing the ICGSE papers do not confirm this conventional wisdom (similarly to architecture and design, and requirements engineering). Therefore, the data shows that ICGSE achieved a certain maturity in selected topics, and the majority of these topics deals with the organization of distributed projects, the empowerment of distributed teams, and barriers and success factors mostly coming along with collaboration

[3]As already mentioned in Sect. II-A, we initially set the thresholds for SoE and ICP to 0.4 to define a baseline. This baseline can however change over time when more in-depth information regarding the actual impact of the different ICGSE contributions is available. This baseline as "artificial" number will also serve the scoping of research activities, e.g., project management is well-researched yet lacking practical confirmation, or agile is of high relevance to industry yet lacks some more research. Furthermore, this baseline will also help to confirm, e.g., whether well-researched topics really impact practice (and how). Therefore, Table V provides an initial evaluation, which can be used by further researchers to fill the gaps (e.g., in project management, agile, or quality), or to replicate studies and confirm findings (e.g., sourcing, collaboration).

TABLE V
RANKED GSE THEMES AND THEIR IMPACT (CATEGORIES: STRENGTH OF EVIDENCE (SOE) AND INDUSTRY COLLABORATION PATTERN (ICP) WITH THRESHOLD 0.4).

Themes	SoE	ICP	relevance	
Processes and Organization	0.52	0.61	✓	✓
Sourcing and Supplier Management	0.51	0.59	✓	✓
Success Factors	0.47	0.55	✓	✓
Collaboration and Teams	0.42	0.53	✓	✓
Communication, Soft Skills	0.47	0.26	✓	
Project Management	0.46	0.36	✓	
Culture	0.44	0.37	✓	
Agile	0.35	0.54		✓
Quality	0.28	0.52		✓
Tools and IT Infrastructure	0.26	0.23		
Knowledge Management	0.23	0.30		
Testing	0.14	0.24		
Requirements Engineering	0.14	0.09		
Education and Training	0.12	0.14		
Architecture and Design	0.09	0.09		

and communication across global and cultural distance. More engineering-related topics, such as design or testing are not yet comprehensively addressed in the ICGSE papers.

In a nutshell, the ICGSE publication body shows a significant impact to industry. A considerable share of ICGSE papers is grounded in academic-industry cooperation in which concepts and new approaches, methods, and tools are disseminated and evaluated in practice [1], [3], [17].

IV. Industry State-of-the-Practice

After having analyzed the big picture of GSE topics and themes and their evolution over time, we provide some practical lessons learned. In this section, we collect and summarize industry state-of-the-practice in GSE. As a basis, we take the previously discussed ICGSE articles from the past decade and aggregate them into meaningful clusters of relevance. Results stem from companies with a published track record in GSE, such as Siemens, Alcatel, Ericsson, Microsoft, but also many small and medium enterprises (see for instance [22]–[25]). We also ground our discussion in the feedback collected from research and industry, as for instance collected in discussions at the different panels of recent ICGSE conferences.

A. Drivers for Going Global

Offshoring and outsourcing are two dimensions in the scope of globalized software development. They do not depend on each other and can be implemented individually. All GSE formats allow for a more flexible management of operational expenses, since resources are allocated at places and in regions where it is most appropriate to flexibly fulfill needs and constantly changing business models [26]. Figure 9 summarizes the reasons for GSE based on data from software companies in Europe and North America [1], [2] (and complemented with further findings, e.g., from [27]–[29]).

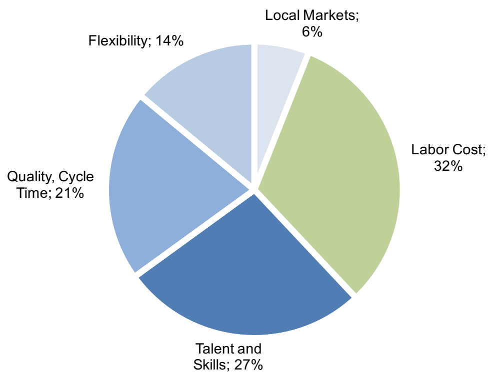

Fig. 9. Reasons for outsourcing and offshoring.

Cost reduction is still the major trigger for globalization, even though its relevance has been decreasing over time. This reasoning is simple and yet so effective that it is mainstream for most companies and media today. Labor cost varies around the globe. For similar skills and output, companies pay a different amount of money per work unit in different places. Looking to mere labor cost for comparable skills of educated software engineers, several Asian countries have a rate of 10-40% of what is paid for the same work in Western Europe or USA. Salary differences theoretically allow reducing R&D labor cost by 40-60% [2]–[4], [30]. However, missing and insufficient competences, hidden costs, and extra overheads severely reduce this potential [31].

B. Going Global: Risks and Chances

While market proximity, cost advantages, and skill pool are still considered beneficial, still, GSE bears risks coming on top of normal project risks [1], [3]:

- 20-40% extra cost at begin of learning curve for 1-2 years
- Over 20% of sourcing contracts are cancelled in first year
- Over 50% of the projects do not deliver according to objectives or strategy and are cancelled downstream
- Over 80% of companies are not satisfied with their global software activities
- Increasing unexpected loss of intellectual property rights (IPR) and technology know-how
- Decreasing proficiency level due to inexperienced hiring

As companies jump on GSE, they find the process of developing and launching new products and services increasingly complex, as they have to integrate skills, people, and processes scattered across different sites. If not sufficiently prepared, after a while, many companies realize that savings are much smaller than expected and problems are more difficult to cure than before [28], [29], [31]. Therefore, disillusioned many companies stop their engagement in GSE. The ICGSE industry panel showed that around the globe 20-25% of all outsourcing relationships fail within the first two years and 50% fail within five years [1], [2]. This is supported by studies reporting a trend towards localization and insourcing [3], [4].

C. Reasons for GSE Failure

Globally distributed projects often fail when tasks were broken down into too small chunks, e.g., asking a remote engineer to verify software concurrently developed at another site [1]. In such cases, distance and lacking direct communication hinder development activities. Communication across project sites is the most remarkable barrier for outsourcing and offshoring. That is, inefficient communication hinders both coordination and management processes. The GSE-related challenges and major reasons for project failure can thus be summarized as follows [2], [16]–[19], [28], [29], [32], [33]:

- Project delivery failures
- Insufficient quality
- Distance and culture clashes
- Staff turnover
- Poor supplier services
- Instability with overly high change rate
- Insufficient competences
- Wage and cost inflation
- Lock-in
- Inadequate IPR management.

D. The Cost of GSE

So far, big savings in GSE have been reported only from (business) processes which are well defined and already performed before offshoring started, and which need not much control [4], [17]. This includes maintenance projects (given that the legacy software has some sort of description) where some or all parts could be distributed, technical documentation (i.e., creation, knowledge management, packaging, translation, distribution, maintenance), or validation activities. Development projects have shown good results in those cases where tasks have been separated to provide distributed teams with ownership and clearly defined goals [34], yet, some overhead is to expect from distributed projects [35].

Considering these challenges, actual cost reduction from GSE is much less than the expected potential savings of 40-60% if the same process is split across the globe with changing responsibilities [1], [2], [30]. Successful companies report a 10-15% cost reduction after a 2-3 year learning curve and, initially, outsourcing might add up to 20% extra efforts. The learning curve for transferring a whole software package to a new team (e.g., location) takes about 12 months [1], [2], [4]. For instance, the learning curve for effectiveness in software design and coding allows for reaching 50% effectiveness after 1-3 months and 80% after 3-5 months. The speed also depends on process maturity and technology complexity (yet, the actual process applied seems to be of little impact [36] and is often selected in non-systematically anyway [37], but a process transition offers benefits and bears risks [38]). Each of the following bullets accounts for a 5-10% increase of cost compared to regular onshore cost in the home country [1], [2]:

- Supplier and contract management
- Coordination and interface management
- Fragmented and scattered processes
- Project management and progress control
- Training, knowledge management, communication
- IT infrastructure, global tools licenses
- Liability coverage, legal support.

E. Best Practices for Mitigating GSE Risks

Risk management is the systematic application of management policies, procedures and practices to the tasks of identifying, analyzing, evaluating, treating, and monitoring risk. Global development projects pose specific risks on top of regular risk repositories and check lists (Sect. IV-B). Looking to the articles of the past 10 ICGSE conferences dealing with different risk mitigation strategies (e.g., [16], [39]–[41]), we distilled a framework of nine best practices to mitigate the GSE risks. Figure 10 shows nine factors, which had highest appearance rate in all articles, grouped in a 3×3 matrix where these nine techniques are mapped to three success factors (competences, communication and collaboration) and three benefits (flexibility, innovation and efficiency).

Benefits \ Success Factors	Competences	Communication	Collaboration
Flexibility	Strong Team	Results-driven Leadership	Suitable Soft Skills
Innovation	Continuous Knowledge Management	Value and Customer Orientation	Reliable Partners
Efficiency	Good Process Capabilities	Transparent Organization	Optimized IT Infrastructure

Fig. 10. GSE risk mitigation: industry experiences from 10 years of ICGSE.

V. Conclusion and Trends

In this paper, we analyzed 10 years of ICGSE, and we looked for the themes addressed in the past decade, accumulated knowledge, and trends. We complemented our analysis with a discussion of the current state-of-the-practice, which is grounded in recently published studies and discussions from the various panels of the ICGSE conference. The analysis of the ICGSE papers revealed that the ICGSE conference series addresses both conducting high-quality research, but also fostering the transfer of established Software Engineering concepts, methods, practices, and tools to the GSE context. Among 15 themes that were defined using a cluster analysis, Collaboration and Teams, Processes and Organization, Sourcing and Supplier Management, and Success Factors were identified as well-researched with high relevance to industry. We conclude that research reported at ICGSE addresses the organization of distributed projects and the success factors and barriers to care about the most. However, beyond these more organizational aspects, the ICGSE community also works on concepts and tools to support the transition from "classic" SE to GSE, and the community puts significant effort in collecting, aggregating and structuring knowledge, which is to a large extent grounded in applied research and which helps companies mastering GSE.

A. Limitations

The present study has some limitations that need to be discussed. In particular, the study at hand utilized the well-known instruments for conducting secondary studies, reused proven classification schemas, and followed rigorous methods to analyze and report data. However, as the study is focused on the ICGSE publication pool only, we cannot claim to present the full picture, as we did not include further publications in our study, e.g., journal articles or conference papers published at other venues. Another limitation is the foundation of our analysis in literature and selected open discussions only. This also affects the notion of rigor, relevance, and impact. All numbers and classifications presented in this paper have to be handled with care, as our classification can only provide indication. Yet, it remains unknown whether the present classification reflects the actual situation in practice properly. Interviews or other more structured forms of expert-based information gathering was not employed in this study, but would be necessary to confirm the findings present in the paper at hand. Those limitations however motivate further research (for which our current classification and ranking provides the first baseline) to round out a more comprehensive picture in future.

B. Implications and Future Development of GSE

Global Software Engineering will evolve towards a standard engineering management method, which must be mastered by every R&D manager. Processes and product components will increasingly be managed in a global context. Suppliers from many countries will evolve to ease setting up and operate GSE even for small and mid-sized enterprises in the high-cost countries. Brokers will emerge that help finding partners in different parts of the world and managing the offshoring overheads. However, working in a global context obviously has advantages but also drawbacks. While the positive side accounts for time-zone effectiveness (as for instance claimed by the Follow-the-Sun paradigm [42], [43]) or reduced cost in various countries, we should not close our eyes in front of risks and disadvantages (Sect. IV-B). The business case of working in a low-cost country is surely not a simple trade-off of different cost of engineering in different regions. Many companies struggle because they just looked to the perceived cost differences in labor cost, but not enough on risks and overhead expenses coming along with the more complex project organization. Approximately 20% of all globalization projects are cancelled within the first year, and about 50% are terminated early. In many cases, the promise of savings has not matched the diminishing returns of unsatisfied customers. Many factors cannot be quantified or made tangible initially, but will sooner or later heavily contribute to the overall performance, and practitioners recognize the difficulties. There is a simple rule: *Only those who professionally manage their distributed projects will succeed in the future*.

Furthermore, it needs to be taken into account that cost per headcount will stay low for few years, but will steadily increase in future due to rising living standards in the emerging countries contributing to GSE's growth: *GSE has a strong contribution in improving living conditions around the world*. Bridging the divide is best approached by sharing values and understanding of culture, which is constantly subject to discussion at ICGSE as well, e.g., [44], [45]. Increasing standards of living in China, India and many other of today's low-cost countries will generate hundreds of millions of new middle class people with an increased demand for more IT.

The journey has begun, but it is far from being clear where it will end. Clearly, some countries will come to saturation, as GSE essentially means that all countries and sites have their fair chance to become a player and compete on skills, labor cost, innovativeness, and quality. Software Engineering is based upon a friction-free economy with any labor being moved to that site that is best suited regarding the actual constraints. No customer is anymore in a position to judge that a piece of software from a specific site is better or worse that software produced somewhere else in the world. In a nutshell, the old-economy labeling of "Made in [country x]" has become legacy thinking not applicable to software industries. What counts are business impact and performance, such as resource availability, productivity, innovativeness, quality of work performed, cost, flexibility, skills, and the like.

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