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Search. Review. Repeat? An Empirical Study of Threats to Replicating SLR Searches

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Abstract A systematic literature review is an empirical method used to provide an overview of existing knowledge and to aggregate evidence within a domain. For computer science, several threats to the completeness of such reviews have been identified, leading to recommendations and guidelines on how to improve their quality. However, few studies address to what extent researchers can replicate a systematic literature review. To conduct a replication, researchers have to first understand how the set of primary studies has been identified in the original study, and can ideally retrieve the same set when following the reported protocol. In this article, we focus on this initial step of a replication and report a two-fold empirical study: Initially, we performed a tertiary study using a sample of systematic literature reviews in computer science and identified what information that is needed to replicate the searches is reported. Based on the results, we conducted a descriptive, multi-case study on digital libraries to investigate to what extent these allow replications. The results reveal two threats to replications of systematic literature reviews: First, while researchers have improved the quality of their reports, relevant details are still missing—we refer to a *reporting threat*. Second, we found that some digital libraries are inconsistent in their query results—we refer to a *searching threat*. While researchers conducting a review can only overcome the first threat and the second may not be an issue for all kinds of replications, researchers should be aware of both threats when conducting, reviewing, and building on systematic literature reviews.

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1 Introduction

In the medical domain, systematic literature reviews are an established method to consolidate knowledge of existing empirical studies before conducting a new one (Babar and Zhang 2009; Sackett et al 1997; Webster and Watson 2002). Over time, other domains, such as social sciences, criminology, and software engineering, have adopted the use of systematic literature reviews as a methodology and derived corresponding guidelines (Babar and Zhang 2009; Dybå et al 2005; Kitchenham and Charters 2007; Kitchenham et al 2009; Webster and Watson 2002). Systematic literature reviews are a suitable way to identify, compare, and summarize the findings of studies that address a specific problem. By following defined guidelines, researchers can systematically collect papers on such a problem, consolidate the provided information, and identify research opportunities (Boell and Cecez-Kecmanovic 2015; vom Brocke et al 2015; Kitchenham and Charters 2007; MacDonell et al 2010).

Systematic literature reviews as an empirical research method have gained growing interest in the software-engineering research community, indicated by an increasing number of such papers being published (Budgen et al 2018a; Kitchenham et al 2009, 2010; da Silva et al 2011; Zhang and Babar 2013). A systematic literature review aims to provide an unbiased analysis and follows a well-defined methodology (Kitchenham and Charters 2007; Kitchenham et al 2016) that can be replicated by other researchers and, in an ideal world, would result in the same outcome if no parameters are changed. For instance, Kitchenham et al (2011) explicitly highlight repeatability as an anticipated benefit of a systematic literature review, but also find that this is hardly achievable. While all steps of a systematic literature review are equally important, the first step of searching relevant papers arguably has significant impact on the outcome, for example, due to important papers being missed (Badampudi et al 2015; Felizardo et al 2016; Jalali and Wohlin 2012). A literal replication or repeat[1] (Gómez et al 2014) of a search may be neither desirable nor possible (Kitchenham et al 2011, 2016; Lindsay and Ehrenberg 1993; Riedl 2007), for example, considering limitations of digital libraries (Kitchenham and Charters 2007; Shakeel et al 2018). However, independently of the actually applied replication strategy (Gómez et al 2014; Riedl 2007), it is important to have the necessary information of the original setup (e.g., search strings) and be aware of technical limitations. In this context, we know of only few studies that are concerned with analyzing threats to searches and their repeatability. Such knowledge is necessary for researchers conducting, reviewing, reading, replicating, and extending a systematic literature review to assess potential threats to the original study, replications, extensions, and comparisons between all of these, with comparisons being recommended for experimental replications (Carver 2010).

Research Goal In this article, we investigate the initial step of searching primary studies for a systematic literature review in computer science, focusing on two research questions:

RQ_1 *Do researchers report information needed to replicate the search of a systematic literature review?*
To replicate a systematic literature review, several pieces of information are necessary. With this research question, we aimed to provide an overview of what information is

[1] `https://www.acm.org/publications/policies/artifact-review-badging`

described in systematic literature reviews that allows replicating the initial search process, for example, guidelines, search strategies, and search strings. We report details on the study design in Section 4 and discuss the results in Section 5.

RQ_2 *To what extent can we replicate searches on literature resources?*
The results of our study show that automatic searches in digital libraries are the most common search strategy. Consequently, they are an essential factor when replicating a systematic literature review. We conducted a descriptive multiple-case study (Yin 2018) to assess the extent to which researchers can replicate automatic searches and report the details in Section 6.

By answering these research questions, we empirically analyzed to what extent researchers can replicate the search processes of systematic literature reviews. To this end, we applied a two-step methodology: First, we performed a systematic literature review on other systematic literature reviews—a *tertiary study* (Kitchenham et al 2016)—to assess what information researchers report. Second, based on the results of our tertiary study, we designed and conducted a descriptive multiple-case study on digital libraries to evaluate the possibility to replicate automatic searches in these.

Overall, we contribute the following with this article: We provide an overview on information that researchers report in systematic literature reviews, namely the guidelines, search strategies, literature resources, and search strings that were used, as well as problems the researchers faced during the conduct. The results indicate multiple threats in reporting systematic literature reviews that need to be addressed. While other studies already show that literature resources in computer science do not support the systematic literature review process sufficiently (Kitchenham and Brereton 2013; Shakeel et al 2018; Zhang and Babar 2010), they do not investigate the consistency of search results. Thus, we analyzed whether we could replicate systematic literature reviews that relied on automatic searches, with our results indicating that this seems hardly possible.

Outline The remaining article is structured as follows. In Section 2, we introduce the general concepts that are necessary to understand this article. Within Section 3, we provide an overview of related work, putting our own work into context and providing additional motivation. Afterwards, we report the design and conduct of our tertiary study within Section 4 and Section 5, respectively. Based on the results we obtained in this tertiary study, we conducted a descriptive multiple-case study to analyze literature resources, for which we report the details in Section 6. We summarize our findings in Section 7 to conclude this article.

2 Background

In this section, we introduce the concepts that are important to understand this article. To this end, we describe the purpose of a systematic literature review and its phases, different search strategies, and literature resources.

2.1 Systematic Literature Reviews

A systematic literature review is an empirical method to systematically identify papers related to a certain research question to evaluate, consolidate, and interpret the existing evidence (Kitchenham and Charters 2007; Kitchenham et al 2016). The investigated papers are

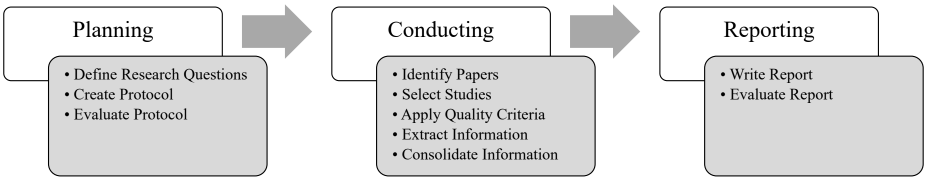

Fig. 1 Phases of a systematic literature review according to Kitchenham et al (2016).

referred to as primary studies, while the systematic literature review itself is a secondary study. Independent of the domain, systematic literature reviews are helpful to identify the state of the art on a research topic and to reveal opportunities for further investigations (Boell and Cecez-Kecmanovic 2015; vom Brocke et al 2015; Webster and Watson 2002).

In contrast to narrative reviews that summarize the experiences and insights on a topic from an expert's perspective (vom Brocke et al 2015; Collins and Fauser 2005), systematic literature reviews aim to be more systematic to avoid biases (Booth et al 2012) that may occur, for example, due to identical author risk (Jalali and Wohlin 2012) or "cherry-picking" (Kitchenham et al 2016). Consequently, systematic literature reviews require the researchers to (Kitchenham and Charters 2007; Kitchenham et al 2016):

– Construct a review protocol before the conduct;
– Define a search strategy to identify papers;
– Explain inclusion and exclusion criteria to select papers;
– Define quality criteria to evaluate the papers; and
– Describe the review and evaluation process within the protocol.

Overall, the goal of a systematic literature review is to aggregate existing evidence on a research topic, while mitigating threats of deriving biased results. In particular, the structured protocol enables replications and allows verification of the results by other researchers.

Still, conducting a systematic literature review is a demanding task that poses difficulties to novices and experienced researchers alike (Biolchini et al 2005; Dybå and Dingsøyr 2008; Kitchenham and Charters 2007; Riaz et al 2010). To facilitate the conduct of systematic literature reviews, guidelines have been proposed to help researchers with defined phases and steps. The guidelines by Kitchenham and Charters (2007) and their updated version (Kitchenham et al 2016) are widely adopted for software engineering and many systematic literature reviews have been based on them (Kitchenham et al 2009, 2010), wherefore we also rely on these guidelines. A systematic literature review comprises three phases, as we depict in Figure 1.

Planning. Before starting a systematic literature review, the researchers have to identify its necessity, mainly investigating that the considered topic has not been reviewed recently and that such a review is needed. Then, the planning phase starts with defining the research questions to scope the extent of the systematic literature review. Based on these questions, the conducting researchers write a review protocol, addressing: motivation, research questions, search strategy, selection criteria, quality criteria, data extraction, information consolidation, threats to validity, type of the review, and additional management activities. As a result, they create a detailed plan for the systematic literature review and, in a final step, evaluate it.

Conducting. After the planning phase, the researchers execute the steps they defined in the protocol. Thus, they identify relevant papers based on the search strategy and assess these papers for relevance by applying selection and quality criteria. From the resulting relevant papers, the researchers extract and consolidate all important information. As a result, they collect the information that is necessary to answer the previously defined research questions.

Reporting. Finally, the conducting researchers use the consolidated information to answer the research questions. To this end, they need to focus on the contribution of the systematic literature review to the investigated domain, new findings, and have to reason about the validity of the results (Shaw 2003). To document the outcome, the researchers write a protocol that comprises the answers to these aspects and the research questions. Finally, the researchers evaluate the report to ensure that it fulfills all requirements and that they performed the systematic literature review as defined in the planning phase.

2.2 Search Strategies

Identifying relevant papers is an essential step in any systematic literature review. Researchers define this step in the search strategy, which they have to adapt according to the goal of the systematic literature review (vom Brocke et al 2015; MacDonell et al 2010). In this article, we differentiate between three core strategies that researchers can use independently or in combination (Kitchenham et al 2016):

- *Automatic Search*
  For an automatic search, researchers define a search query and execute it on a digital library or database. The advantage of this search strategy is its speed and limited effort to identify a large number of papers. However, automatic searches also include large numbers of irrelevant papers that must be manually filtered (Kitchenham and Charters 2007). In addition, the quality of the results depends on several factors, such as the libraries and databases that the researchers use, the search query and its adaptations, the existence of synonyms, as well as duplicates (Jalali and Wohlin 2012; Shakeel et al 2018; Zhang et al 2011).
- *Manual Search*
  A manual search is limited to defined venues, for example, a set of Journals or Conferences. Consequently, researchers manually collect and evaluate each paper from the selected venues to identify whether it is relevant for the systematic literature review. Such a manual search requires less effort than an automatic one, if a limited and appropriate set of venues is selected. Still, each paper must be manually evaluated and inconsistent usage of keywords, poor quality of abstracts, and synonyms can pose problems (Brereton et al 2007).
- *Snowballing*
  For snowballing, an initial set of relevant papers must exist. Then, researchers can analyze the papers' references (backwards-snowballing) or their citing papers (forwards-snowballing) to identify further papers (Jalali and Wohlin 2012; Wohlin 2014). This process can be performed incrementally, continuing with the newly identified papers of each iteration. Essential for this search method is the initial set of papers that should be based on different communities, publishers, years, authors, and not too small (Wohlin 2014). The advantage of this method is its simplicity, but depending on the number of referencing and citing papers, it can become an extensive analysis compared to an automatic search (Badampudi et al 2015).

Researchers can use each of these search strategies to identify relevant papers for a systematic literature review. Due to the limitations and disadvantages of each method, several authors and guidelines recommend to combine different search strategies (Jalali and Wohlin 2012; Kitchenham et al 2016; Zhang and Babar 2010).

2.3 Literature Resources

In the previous section, we referred to digital libraries and literature databases. For simplicity, we summarize these terms and any other collection that provides long-term access to scientific literature and that can be searched for a systematic literature review as *literature resources* in the remaining article. While such literature resources are essential, they have several shortcomings that hamper their usability for systematic literature reviews. This includes, for example, different search models and query syntaxes (Babar and Zhang 2009; Brereton et al 2007; Falagas et al 2008; Imtiaz et al 2013; Shakeel et al 2018), limitations for complex queries (Falagas et al 2008; MacDonell et al 2010), varying publisher coverage (Falagas et al 2008), missing standard keywords (Kitchenham and Brereton 2013), and permanent development, including sudden expiration (Giles 2006; Harzing and Alakangas 2017; Orduña-Malea et al 2014). In particular, all these issues are rarely communicated or documented, and thus researchers are seldom aware of these issues until they face those (Orduña-Malea et al 2014). As such problems are known, researchers that conduct a systematic literature review can address them. In contrast, only the providers of literature resources can influence whether these behave consistently. Still, inconsistency is a potential threat that may influence automatic searches for a systematic literature review, which is why we conducted an empirical study on this issue.

3 Motivation and Related Work

The motivation for our study was to investigate the ability of researchers to replicate the search of a systematic literature review. We focused on this first step of conducting a systematic literature review, as it scopes the set of papers, and thus the available evidence. In this section, we discuss related work, highlight the differences to our study, and provide additional motivation.

Kitchenham et al (2011) highlight that achieving repeatability may not be the goal of a systematic literature review in software engineering, but is an expected characteristic. Similarly, Booth et al (2012) characterize that a systematic literature review is reproducible, in contrast to other forms of reviews. While literal replications (Yin 2018) are not always intended and are hardly possible, it is still important to understand threats that hamper replications—independent of their purpose and design, for example, literal replications or extensions. Such threats are connected to the reporting of systematic literature reviews or technical limitations, as we highlight based on the following related papers.

Jalali and Wohlin (2012) compare an automatic search to backwards-snowballing, both with one iteration. They identified 26 and 15 unique papers, respectively, as well as 27 common papers. While they could derive similar patterns from both searches, each search individually missed some important papers and would provide an incomplete overview, among other threats to each search strategy. Similarly, Badampudi et al (2015) compare those two search strategies in the context of systematic mapping studies. They identified 45.9% of the relevant papers using an automatic search, while snowballing revealed 83%. The authors also derived conclusions based on the identified papers and found that the overlap was quite small (5 out of 15 compared conclusions). More importantly, only snowballing revealed conflicting primary studies and seemed to be more reliable (14 out of 15 compared conclusions). Felizardo et al (2016) applied forwards-snowballing and an automatic search to update an existing systematic literature review. Contrary to the two previous studies, they found that snowballing may reduce the effort, but may miss important papers. Thus, it seems unclear, which search strategy is more useful for systematic literature reviews. Finally, comparing the same procedure of combining automatic search and snowballing with two different teams, MacDonell et al (2010) conclude that systematic literature reviews are robust and repeatable, as both teams derived the same findings. These works highlight the impact of missing papers in the search process and the importance of ensuring its consistency.

Considering reporting, some tertiary studies indicate that, despite an increase in quality, important details in reports of systematic literature reviews are still missing, preventing full understanding (Budgen et al 2018a; Kitchenham et al 2010). These studies already indicate the importance of knowing potential threats to the initial search and its reporting in systematic literature reviews to ensure reliable evidence, but also to provide details for scoping replications and extensions. A rather different example is the tertiary study conducted by Budgen et al (2018b). The authors focus on the importance of industrial case studies for systematic literature reviews and highlight that, in order to improve the relevance for practitioners, different reporting strategies are required, such as a specific summary of findings (von Nostitz-Wallwitz et al 2018).

Other tertiary studies investigate the general development of systematic literature reviews in software engineering and are related to our work (Kitchenham and Brereton 2013; Kitchenham et al 2009, 2010; da Silva et al 2011). However, these works are more concerned with statistics about publication venues, authors, and the general quality of the provided information. Some authors, such as Budgen and Brereton (2006), Brereton et al (2007), Dybå et al (2007), Babar and Zhang (2009), MacDonell et al (2010), Imtiaz et al (2013), and Shakeel et al (2018), report their experiences, conduct tertiary studies, or interview experts to analyze the application and problems of systematic literature reviews. For example, these studies identify some issues of the applied search strategies, search models, APIs, and adaptations of search strings.

As we described, there have been some studies on the repeatability, search strategies, and reporting of systematic literature reviews. While some of these works have an overlap with our research questions, none of them is focusing on the details that researchers report on the search processes or the consistency of literature resources. The existing studies show that different searches can have an impact on the results researchers derive from a systematic literature review. Thus, this initial step is important to analyze further, helping us to understand threats, especially to their replication.

4 Tertiary Study: Design

As first step of our study, we conducted a systematic literature review, aiming to answer our first research question and scoping our case studies for the second research question. In Figure 2, we depict the review protocol process of our systematic literature review that we use to report the steps we performed during the conduct (cf. Figure 1). In this section, we describe each of these steps in detail. At the beginning, we refined our first research question to scope our study and describe the resulting sub-questions in Section 4.1. Afterwards, we defined a search strategy to identify suitable papers, as we report in Section 4.2. In Section 4.3 and Section 4.4, we describe our selection and quality criteria, respectively. Finally, we present how and what data we extracted and aggregated in Section 4.5.

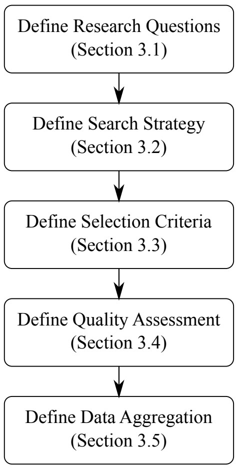

Fig. 2 Review protocol content for systematic literature reviews based on Brereton et al (2007).

4.1 Research Questions

The purpose of our review was to investigate whether researchers report the pieces of information that others need to replicate the search of a systematic literature review. Consequently, we performed a secondary study on secondary studies, which Kitchenham et al (2016) refer to as *tertiary study*. To scope our tertiary study, we refined our first research question, focusing particularly on details about the search. We defined five sub-questions based on previous works and our own experiences (cf. Section 3):

$RQ_{1.1}$ *What guidelines do researchers use to conduct systematic literature reviews?*
Several authors have proposed guidelines for conducting systematic literature reviews in various domains, for example, Webster and Watson (2002) in information systems or Kitchenham and Charters (2007) in software engineering. With this research question, we aimed to identify what guidelines researchers follow and whether one is dominating in computer science. Conducting a systematic literature review without any guidelines or based on varying (e.g., versions or variants) guidelines may hamper researchers' ability to understand and replicate the process, for example, because information and even phases differ or were added only in later versions (Dresch et al 2014; Kitchenham et al 2016).

$RQ_{1.2}$ *What search strategies do researchers employ?*
As we described in Section 2.2, three main strategies and their combinations exist to search for relevant primary studies: *automatic search*, *manual search*, and *snowballing*—each strategy having different pros and cons. Consequently, it is essential that researchers specify the search strategy that was employed in order to support replications. We identified how often researchers have employed which search strategy and in which combinations.

$RQ_{1.3}$ *What literature resources do researchers use to search for relevant papers?*
In addition to the employed search strategies, we were also interested in the literature resources used. As such resources develop over time (Fuhr et al 2007; Harzing and Alakangas 2017; Orduña-Malea et al 2014) and are seen as differently important for systematic literature reviews (Brereton et al 2007), we aimed to identify what re-

sources have been commonly considered. This provides an overview for researchers and is—in combination with our descriptive multi-case study—a means to assess validity threats of searches that are performed for systematic literature reviews.

$RQ_{1.4}$ *What information on search strings do researchers provide?*
The search string is the essential input for any automatic search. We investigated which details researchers report on the used search string, namely whether they provide a *search query*, only *keywords*, or even *no information* at all. This granularity indicates whether an existing systematic literature review can be replicated, especially if it remains unclear how the researchers constructed a search string or adapted it for different literature resources. We investigated adaptations of search strings within this and the next sub-question.

$RQ_{1.5}$ *What problems do researchers report?*
Finally, we were also interested in problems other researchers experienced while conducting systematic literature reviews. We read each paper and gathered reported experiences to summarize challenges and pitfalls. This can help researchers when conducting systematic literature reviews, replications or extensions, and indicates research opportunities for future work.

Overall, answering these research questions has four purposes. First, we provide an overview on details reported on the search processes of systematic literature reviews that are necessary to replicate these. Second, we show what threats to validity may exist, due to missing information. Third, we derive recommendations for assessing and conducting especially automatic searches for systematic literature reviews to ensure that researchers can replicate them and that they are consistent. Fourth, we used the results to scope our descriptive multiple-case study for our second research question (cf. Section 6).

4.2 Search Strategy

To answer our research questions, we conducted an automatic search in Scopus.[2] Scopus indexes papers of different publishers, for instance, ACM, IEEE, Springer, and Elsevier, that are previously assessed by an independent committee. As a result, all papers should have a certain quality, as at least two reviews have been performed: The papers have been reviewed to be accepted at a venue and the venue itself to be included in Scopus. We applied the following search string.

```
TITLE-ABS-KEY(‘‘systematic literature review’’ OR ‘‘tertiary study’’) AND
(LIMIT-TO(SUBJAREA, ‘‘COMP’’) ) AND
(LIMIT-TO(PUBYEAR, 2016) OR LIMIT-TO(PUBYEAR, 2015))
```

Thus, we restricted our results to papers that explicitly mention a systematic literature review or tertiary study in their title, abstract, or keywords. In addition, the papers had to be published and be available in Scopus from 2015 to June 2016 (we conducted our query in July 2016), and address the domain of computer science. We remark that we considered not only software engineering, but computer science as a whole, to provide a broader overview and avoid disagreement on what areas are still part of software engineering research. To avoid this problem, we followed the classification of Scopus that, however, may also not be ideal. Nonetheless, our results mainly comprise papers that are based on the guidelines by Kitchenham and Charters (2007), indicating that software engineering is the major contributor of systematic literature reviews in our set of papers.

[2] `https://www.scopus.com/home.uri`

4.3 Selection Criteria

We excluded any paper that did not fulfill all of the following inclusion criteria:

- The paper is written in English;
- The publication year is 2015 or 2016;
- The paper addresses the domain of computer science; and
- The paper describes the conduct of a systematic literature review.

We focused on the period preceding the date of our search to consider current developments and limited the period to one and a half year, as several studies show an increasing number of systematic literature reviews being published in software engineering (Babar and Zhang 2009; Budgen et al 2018a; Kitchenham et al 2009, 2010; da Silva et al 2011). As we analyzed the applied search strategies—not a specific research question—of a systematic literature review, we expected a large number of relevant papers even for this short period. Moreover, we excluded irrelevant papers, especially if they only discuss the results of a systematic literature review, but do not report how the conduct was performed.

4.4 Quality Assessment

Scopus only indexes papers from venues that have been examined by an independent committee. Due to the two review phases for each paper, we assume that all of them have a certain quality. Identical to other researchers (Kitchenham and Brereton 2013), we did not exclude papers based on quality criteria—wherefore we did not define such criteria. We did this because our research questions address the quality of the papers. Thus, excluding them in advance would bias the results, which reflect quality criteria to a certain extent.

4.5 Data Aggregation

We added each paper into a reference management tool, namely *Zotero*.[3] With this tool, we automatically collected the following standard information: *title*, *authors*, *publication year*, and *venue*. To answer our research questions, we first read each abstract to exclude papers not fulfilling our exclusion criteria and, if necessary, each paper completely. In accordance with proposals of other researchers (Brereton et al 2007; Kitchenham et al 2009), one of the authors then extracted the relevant data, while the others reviewed the results. These reviews were based on two of the other authors verifying random samples of papers and all authors checking the completeness of the extracted data. We resolved conflicts by first checking the corresponding papers again and, in few cases, had to decide by majority vote. Overall, we extracted the following data:

- The guidelines used for the systematic literature review if the researchers explicitly report to follow and cite them.
- The search strategy (i.e., automatic, manual, snowballing) the researchers employed.
- The literature resources in which the researchers searched for relevant papers.
- The information on search strings (i.e., search string, keywords, none).
- The problems the researchers report about conducting the systematic literature review.

[3] `https://www.zotero.org/`

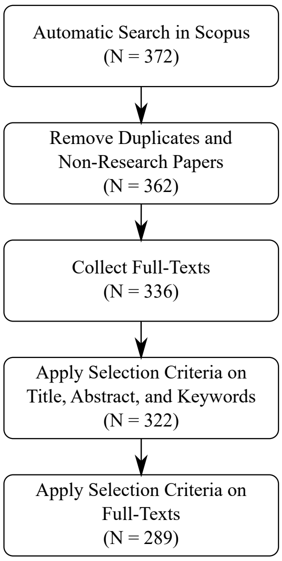

Fig. 3 Conduct phase of our tertiary study.

This information allows us to answer our first research question and its sub-questions. To store the corresponding data, we first added tags in the Zotero database. For our analysis, we automatically migrated the data into an SQL database and used queries to consolidate the information for each research question.

5 Tertiary Study: Conduct and Results

In this section, we first describe the conduct of our tertiary study (cf. Figure 1). We then present and discuss the results we obtained for each sub-question, describe threats to the validity of our systematic literature review, and finally answer our first research question to summarize the results.

5.1 Conduct

Based on the protocol we described in the previous section, we executed our automatic search on July 5th 2016. We illustrate the steps of our conduct in Figure 3. As we show, our automatic search on Scopus resulted in 372 papers that matched our search string. In the next step, we imported all papers into Zotero, removing duplicates and non-research literature, such as, tables of contents and proceeding introductions. For this reason, we removed 10 papers from our initial set. Then, we downloaded all full-text versions we had access to, which was not the case for 26 of the papers. Afterwards, we read the title, abstract, and keywords of each paper and excluded 14 that did not match our defined inclusion criteria (cf. Section 4.3). Finally, we applied our inclusion criteria on the full texts of all remaining 322 papers, of which we excluded 33. Consequently, we identified 289 papers to be relevant for our study, spanning one and a half year of research based on systematic literature reviews. We provide a list of all included papers in the Appendix of this article.

Table 1 Guideline used and referred to in the analyzed systematic literature reviews.

ID	Guidelines	Usage		Domain
		Total	Relative	
1	Kitchenham and Charters (2007)	192	66.4%	Computer Science
2	Webster and Watson (2002)	9	3.1%	Computer Science
3	Tranfield et al (2003)	9	3.1%	Economics
4	Biolchini et al (2005)	4	1.4%	Computer Science
5	Khan et al (2003)	4	1.4%	Medicine
6	Moher et al (2009)	3	1.0%	Medicine
7	Okoli and Schabram (2010)	3	1.0%	Computer Science
8	Booth et al (2012)	2	0.7%	Medicine
9	Petersen et al (2008)	2	0.7%	Computer Science
10	Levy and Ellis (2006)	1	0.3%	Computer Science
11	Soni and Kodali (2011)	1	0.3%	Economics
12	Galvan and Galvan (2016)	1	0.3%	Social Sciences
13	Wolfswinkel et al (2013)	1	0.3%	Computer Science
14	Bandara et al (2011)	1	0.3%	Computer Science
	None	60	20.8%	

5.2 $RQ_{1.1}$: What guidelines do researchers use to conduct systematic literature reviews?

Measurement To answer this research question, we read each paper in detail and identified whether the researchers followed a guideline. We considered this to be true, if both of the following conditions applied:

- The researchers explicitly write that they follow a certain guideline.
- The used guideline is cited in the paper.

As some guidelines have been extended, updated or published in different versions (e.g., by Kitchenham and Charters (2007) and Kitchenham et al (2016)), we condensed references to such works of the same (or most) authors to the version that has been published first. In addition, in four papers the researchers state to apply more than one guideline, wherefore we identified more usages of guidelines than investigated papers. Consequently, the numbers in Table 1 add up to more than 100%.

Results We provide an overview of all guidelines that we identified in Table 1, comprising the cited or earliest reference, the number and ratio of papers referring to each guideline, and the domain of the guideline. We remark that the domains reflect broader research areas. Thus, instead of assigning Kitchenham and Charters (2007) to software engineering and Webster and Watson (2002) to information systems, we assigned both to the more general domain of computer science. In our set of papers, researchers most commonly used the guidelines by Kitchenham and Charters (2007) with approximately 66.4% of the analyzed papers referring to these, highlighting the dominance of software engineering in our analysis. Overall, 20.8% of the papers do not mention any guidelines. 14.2% (41) of the papers follow at least one of the other 13 guidelines we identified. In most cases, the researchers applied guidelines that are proposed or adopted for computer science, while some rely on such from economics, medicine, and social sciences.

Discussion In Table 1, we can see that the guidelines proposed by Kitchenham and Charters (2007) are dominating the structure of systematic literature reviews in computer science.

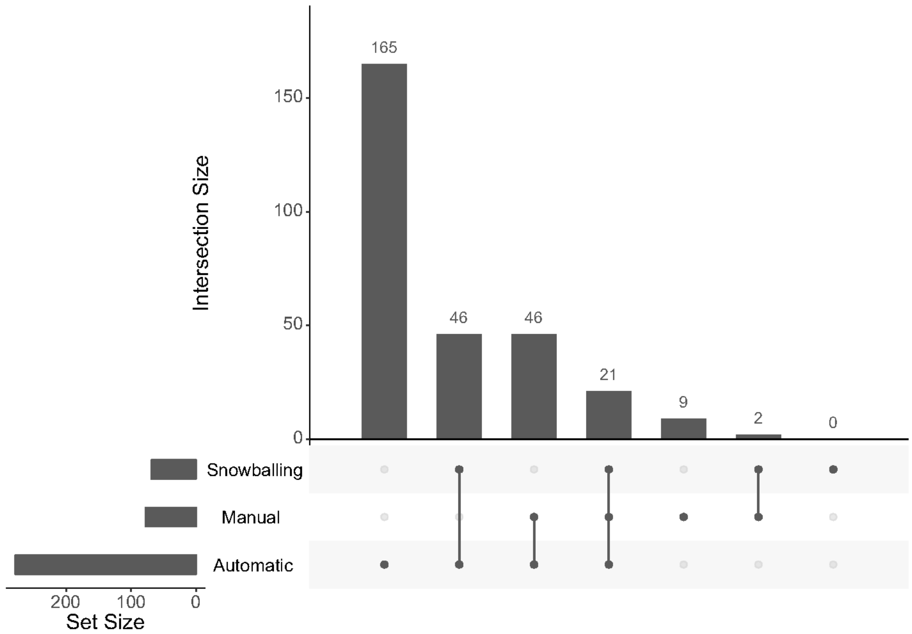

Fig. 4 Profile of search strategies employed in the systematic literature reviews we analyzed.

This is not surprising, as they have been the first to adopt this methodology for software engineering and reason about its suitability for this domain—from which most of the papers we identified originate. The other guidelines we found have been applied due to different and interdisciplinary research topics within the field of computer science, relying on corresponding guidelines. Still, this diversity raises several questions and issues: It seems necessary to compare the structure of the proposed guidelines to identify the extent of commonality and diversity in their processes. Researchers may find it challenging to compare reviews on the same topic if the authors performed and report different steps or if some steps are not explicit (Dresch et al 2014). Another question is whether this large number of guidelines is necessary and useful. For software engineering, and to the extent of this study computer science, the guidelines of Kitchenham and Charters (2007) seem to dominate and may be used or consolidated with the remaining ones to define the standard in computer science.

Another problem arises, as approximately one fifth of all papers we analyzed are not reporting whether a specific guideline was used or not. This is a decrease compared to the findings of Kitchenham et al (2010), who identified that less than half of the investigated systematic literature reviews report them. Nonetheless, such systematic literature reviews hamper the understandability, do not allow the reader to gain background information, and may complicate replications. In summary, while the awareness for guidelines seems to increase, there are still many papers that do not follow or report them.

5.3 $RQ_{1.2}$: What search strategies do researchers employ?

Measurement Again, we read each paper to identify the employed search strategy. In this case, we analyzed the mentioned searches, but also descriptions of the search process—

especially because snowballing is a kind of manual search and researchers may not clearly differentiate these strategies. We identified for each paper whether the researchers employed an automatic, manual or snowballing search (cf. Section 2.2). As before, papers can rely on more than one method, as is also recommended, for example, by Zhang and Babar (2010).

Results We display the numbers of employed search strategies as `UpSet` (Lex et al 2014) plot in Figure 4. The bottom left part illustrates how many papers employed each strategy in total. In the remaining bottom part, `UpSet` plots display interaction sets (combinations) and the bars above show how often each interaction set has been used. Thus, `UpSet` plots are an equivalent representation to Venn diagrams, but are more useful for large sets or if scales cannot be represented properly.

In Figure 4, we can see that the sole automatic search is used the most by far (165 times) and also in almost all combinations (278), except for 11 systematic literature reviews. Manual search and snowballing have been employed almost equally often with 78 and 69 papers relying on them, respectively. However, they mostly occur in combination with automatic searches. A purely manual search was employed only nine times in our set of papers, while a sole snowballing strategy was never used. Combinations of these two methods are also rare, appearing only twice.

Discussion It is positive that every systematic literature review that we investigated clearly defines the search strategy employed. Of these, almost all systematic literature reviews employed automatic searches, arguably because they allow to easily cover many venues. Still, in contrast to manual searches and snowballing, researchers have to provide additional information and must rely on literature resources. In particular, they cannot control the search mechanisms and evolution of these resources—potentially threatening replications of the search process. Also, the researchers have to adapt searches for different literature resources that each cover a subset of the available papers in computer science. This may threaten replications of the search process, due to flaws during the adaptation of search strings and inconsistencies within the literature resources.

5.4 $RQ_{1.3}$: What literature resources do researchers use to search for relevant papers?

Measurement As aforementioned, researchers most often employed automatic searches in the systematic literature reviews that we analyzed. We identified what literature resources have been used by the 278 papers that relied on such an automatic search. Again, we assigned different versions (e.g., CiteSeer and CiteSeerX) to a single literature resource.

Results We display all literature resources that researchers used for automatic searches in our set of papers in Figure 5. To improve readability, we omit 43 literature resources that appear fewer than five times and have been used in 58 papers. Overall, mostly IEEE Xplore, ACM Digital Library, Science Direct, and Springer Link have been used—representing four major publishers for computer science. With Google Scholar, Scopus, and Web of Science follow literature resources that index papers of different publishers. The researchers used interdisciplinary search indexes and publishers less frequently and we often omit these in Figure 5. We remark that Science Direct[4] and Elsevier[5] denote apparently different search en-

[4] `https://www.sciencedirect.com/`
[5] `https://www.elsevier.com/search`

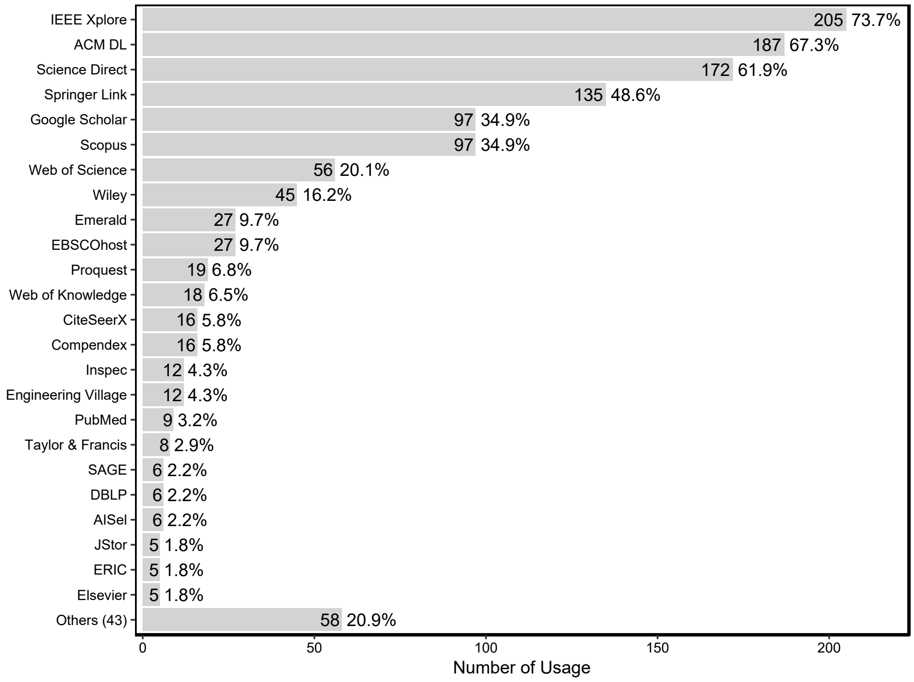

Fig. 5 Distribution of literature resources that were used in the systematic literature reviews we analyzed.

gines, where the first includes only peer-reviewed publications, while the second can also include other resources, such as websites.

Discussion While every paper mentions the literature resources that were searched, the results also indicate multiple threats to the validity of systematic literature reviews conducted with automatic searches. First, while including a broader set of literature resources allows for a more complete overview, it requires adaptations to the search strategy. For example, some literature resources allow searching only on a subset of fields, have a different syntax, and limit the number of results. Thus, to ensure the completeness and possibility of a replication, researchers have to provide the details about adaptations to the search query.

Second, as other findings also indicate (Budgen et al 2018a; Zhang and Babar 2010), many systematic literature reviews rely on the literature resources of the four major publishers in computer science. For our set of papers, we see the same dominance of IEEE Xplore, ACM Digital Library, Science Direct and Springer Link. While this may ensure a certain quality, it can also prevent a complete overview on a research topic. As a result, such systematic literature reviews may face a selection bias and should be extended with snowballing or broader literature resources, such as, Scopus, Google Scholar, or DBLP.

Finally, researchers depend on the interfaces provided by the literature resources. We already described that they can heavily differ and also evolve over time (cf. Section 2.3), potentially preventing replications. In particular, the question arises if the most used literature resources are consistent in the results that can be obtained. As an inconsistent behavior of literature resources would prevent any reliable systematic literature review and its replication, we investigated this issue further with our descriptive multi-case study (cf. Section 6).

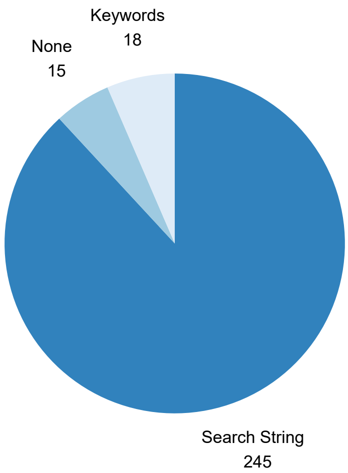

Fig. 6 Reported details about search strings for automated searches.

5.5 $RQ_{1.4}$: What information on search strings do researchers provide?

Measurement To perform an automatic search, a corresponding search string is necessary. For our analysis, we differentiated three levels of information: *None*, *keywords*, and *search string*. We analyzed each paper to identify whether the researchers report a complete search string—including the keywords and their operators (cf. Section 4.2)—or only keywords. Researchers can only perform proper replications of searches if the full search string is described. Otherwise, it is unclear how the original researchers connected keywords or what they even searched for if they provide no information at all.

Results We show the overall outcome of our analysis in Figure 6. As we can see, in 15 systematic literature reviews the researchers do not report any information at all and in 18 other systematic literature reviews the researchers do report only the keywords. Consequently, most researchers report the complete search string they used during their automatic search (245; 88.1%). These search strings mostly contain the simple boolean operators AND and OR, brackets for prioritizing, and enclosures for exact matches. Rarely, other operators—which are also not supported by all literature resources (Shakeel et al 2018)—are used, for instance, to limit the search to certain parts of the document and wild-cards.

Discussion It is positive that most researchers report the full search string they used during their systematic literature review. Only this way, they can mitigate threats to the replication of the searches they employed in a systematic literature review. Researchers in all roles—conductors, reviewers, and readers—should be aware that a fully described search string is an essential requirement. Even better would be to report the search string for each literature resource used, which can take a lot of space. We rarely found papers that provided these adaptations, neither in the papers nor as an appendix. To ensure replications, it is essential to make the adaptations also available, for instance, as an online appendix that could also comprise other artifacts, such as used tools, results, and statistical data.

5.6 $RQ_{1.5}$: What problems do researchers report?

Measurement This question is not directly concerned with replicating the search of a systematic literature review. Instead, we aimed to consolidate the experiences of researchers that conducted systematic literature reviews—with particular interest on those that are connected to the search process. For this purpose, we read each paper carefully and identified all problems or pitfall the researchers reported.

Results Only few researchers mentioned challenges of conducting a systematic literature review. Considering automatic searches, we identified the following problems:

– 35 papers report that it is challenging to adapt search strings to different literature resources, for various of the issues we described.
– Google Scholar allows a maximum of 256 characters (Ilyas and Khan 2015) and does not offer extended filters (Mbiydzenyuy 2015).
– There are several problems and inconsistencies regarding the different literature resources, such as, ACM Digital Library, IEEE Xplore, Science Direct, and Springer Link. For example, the lengths of search strings and options to search within certain parts of the available papers vary and are limited (Abdelmaboud et al 2015; Afzal et al 2016; Soni and Kodali 2011).

Overall, we found only specific problems related to the automatic search strategy and literature resources in computer science. Regarding manual searches and snowballing, some researchers mention that they take a lot of effort, but describe no concrete problems.

Discussion The results show that there are several limitations concerning automatic searches, as has also been discussed by other researchers (cf. Section 3). Because these limitations are related to technical problems, researchers cannot resolve them on their own. Instead, we must report such problems to the providers who can address them. However, manual searches and snowballing can at least mitigate the identified problems. The low number of papers reporting such problems seems surprising, considering that we included 278 automatic searches and how often the researchers used the same literature resources.

5.7 Threats to Validity

Construct Validity The construct validity represents how well the research questions can be understood and addressed with the used methodology—preventing biases of assumptions or design (Kitchenham et al 2016). Our research questions require no previous knowledge about systematic literature review methods. We did not limit our analysis to any specific guidelines, but derived independent, general-purpose questions. Thus, we argue that the construct validity of our tertiary study is not threatened.

Internal Validity Considering internal validity, we only used a single literature resource and a limited period. Furthermore, we excluded any paper that is not related to computer science and its interdisciplinary topics. As a result, we have certainly excluded papers that report a systematic literature review. However, Scopus includes papers of most publishers with a certain quality and we explicitly focused on more recent years to also cope with temporal improvements. Overall, we argue that we are able to answer our research questions and scope our multi-case study based on the findings without threatening their validity.

A factor that we cannot influence is the indexing of literature resources and authors. Thus, some papers may be indexed incorrectly or some systematic literature reviews may be named differently (e.g., "systematic review"), which would both mean that we did not include these papers. Similarly, some of the included papers may actually report systematic mapping studies or even other studies, despite explicitly stating to apply a systematic literature review. However, we investigated all papers in detail, which is why most of such papers have been excluded; and for those still included, the search processes are often identical or similar. Moreover, we included 289 papers and carefully checked the results to avoid selection biases. This way, we aimed to mitigate these threats to the internal validity.

Quite related to our study is one more external threat: Digital libraries may not be updated in time, but add Conference proceedings or Journal volumes only after some time. Thus, it may be that we did not find all papers for the covered period of time. Thus, replications of our study may comprise a larger set of papers. Nonetheless, we included 289 papers and as there is some overlap in their characteristics (e.g., the literature resources used) to other studies, we argue that the results are reliable.

External Validity The results of our tertiary study cannot be generalized to all existing systematic literature reviews. However, this is mainly due to our goal of capturing the more recent development of systematic literature reviews—similar to the works, for example, by Kitchenham et al (2010) or da Silva et al (2011). Due to the ongoing evolution and advancement of systematic literature review methods and literature resources, our results are hard to generalize. However, we present important insights into the current practice and in this context can help to raise the awareness for threats to the search processes used for systematic literature reviews.

Conclusion Validity Considering the results, we argue that they can be replicated by other researchers. We described each step and how we extracted the data to derive the results, which multiple authors controlled. As a result, we argue that the conclusions we derived are not threatened. However, the results can change depending on the considered time period, future developments, and the literature resources included. In particular, the literature resources will be the subject of our following descriptive multi-case study.

5.8 Summary

In the following, we summarize our findings to answer our first research question: *Do researchers report information needed to replicate the search of a systematic literature review?* Considering the results of all sub-questions, we found that often much of the information needed to replicate searches is provided. Nonetheless, there are discrepancies in the details researchers describe and the applied methodologies. We identified the following threats:

1. Approximately 21% of the systematic literature reviews we analyzed did not use or do not report on using a guideline. Consequently, it is unclear whether the used methodology is appropriate. This may also hamper other researchers in replicating a systematic literature review, as guidelines can help to better understand and scope the process.
2. As many guidelines exist, the question arises to what extent they cover the same criteria and details. Differences in the ways the conduct of a systematic literature review is reported may prevent its replication. To address this point, a comparative analysis of existing guidelines seems necessary to identify variations and consolidate them.

3. Most systematic literature reviews solely rely on an automatic search. However, it is questionable if this search strategy covers all relevant papers (Badampudi et al 2015; Jalali and Wohlin 2012; Zhang and Babar 2010). Another potential threat is that literature resources may be inconsistent, a threat that we further addressed with our descriptive multi-case study (cf. Section 6). Comparable to previous studies, we identified that the same literature resources are often used in computer science.
4. While almost all systematic literature reviews report the full search string, we found only few that also report necessary adaptations for different resources. Consequently, other researchers cannot verify that the used search strings were adapted appropriately. This threatens the completeness of the results and hampers replications. We are not aware of a previous study analyzing the reported search strings, wherefore we cannot argue about the temporal development in this regard.

In summary, we conclude that much of the necessary information for replicating the search of a systematic literature review is reported. However, the granularity of details is questionable and many aspects of the search processes are unclear—meaning that replications and extensions have to build on some assumptions. We refer to this as the *reporting threat*, which researchers can overcome by reporting more detailed information.

6 Descriptive Multi-Case Study

Assuming that researchers have provided all information to replicate the search of a systematic literature review, there still remains a potential source of threats: the literature resources that are used. Investigations show that such resources have varying characteristics, for example, in their search models, query design, indexing, and truncation of results (Babar and Zhang 2009; Bailey et al 2007; Brereton et al 2007; Shakeel et al 2018). Thus, it can be challenging for researchers to adapt their search string to each literature resource, as was highlighted in 35 papers we analyzed in our tertiary study. However, a different factor to consider is whether the resources are deterministic, and thus consistently provide the same results for the same queries at different points in time. In order to investigate this issue, we conducted a descriptive multi-case study (Yin 2018) to answer our second research question:

RQ_2 *To what extent can we replicate searches on literature resources?*

Within this section, we describe the setup and conduct of our descriptive multi-case study, report and discuss the results, and analyze threats to validity.

6.1 Setup and Conduct

We focus on two **characteristics** of literature resources that are essential to allow replications: interface consistency and temporal consistency. During our tertiary study, we rarely found information on when exactly a search was performed, whether it was repeated, or through what interface the search was applied. However, if the literature resources do not behave consistently, these factors can have significant impact on the starting set of papers, which may bias the results. For example, we may retrieve varying results depending on the day on which we searched and whether we used the web interface or a tool with a crawler. We investigated these two characteristics as follows:

1. **Interface Consistency.** The results of our tertiary study indicate that researchers use different tools to conduct their searches. We compared the results of applying the same search strings on each selected literature resource using (1) their web interface (*manual*) and (2) through available *APIs*. Thus, we analyzed whether these two interfaces provide the same results, as both may be used by researchers and tools. As ACM did not provide an API when we started our studies, we did not include its digital library in this part of our analysis.
2. **Temporal Consistency.** With this characteristic, we investigated whether repeating a manual or an API search yields the same results. To this end, we compared the papers that we found through each resource and interface at different days. This allowed us to investigate if a replication at any point in time yields consistent results.

To analyze these two characteristics, we designed the following setup for our descriptive multi-case study based on the results of our tertiary study.

Automatic Search We aimed to analyze automatic searches, as most of the identified systematic literature reviews relied solely on this search strategy or used it in combinations. Overall, only 11 systematic literature reviews did not include any automatic search. As aforementioned, we considered automatic searches that may rely on web interfaces or APIs.

Most Prominent Resources We selected the most used literature resources in computer science, according to our results and existing studies (Budgen et al 2018a; Kitchenham et al 2016; Shakeel et al 2018). Furthermore, we limited our selection to the most accessible ones (Shakeel et al 2018), meaning those that have no access restrictions for searches (e.g., excluding Scopus and Web of Science) and that allow to download the results as collections (e.g., excluding Google Scholar). These criteria allowed us to automate parts of the conduct by automatically querying search strings for APIs and comparing the results. Finally, we included *IEEE Xplore* (IEEE), *ACM Digital Library* (ACM), *Science Direct*, and *Springer Link* (Springer).

Search Strings We aimed to cover different research areas in computer science and varying search-string designs. For this purpose, we created five search strings (abstracted):

```
String 1 program comprehension OR debugging OR maintenance AND
         study OR participants AND
         code smells AND
         integrated development environment OR programming language OR
                programming paradigm OR tool
String 2 tool support AND
         keywords: software product line
String 3 security issue OR security issues AND
         keywords: internet of things OR iot
String 4 function call OR graph database AND
         keywords: intrusion detection system OR intrusion detection systems OR
                network security
String 5 keywords: type systems
```

These strings cover different research areas that we are knowledgeable in. We combined the keywords between operators to enforce searching for exact string matches (e.g., program comprehension becomes "program comprehension") to limit the number of results.

Then, we tested whether the queries retrieved varying numbers of papers and followed the restriction of most literature resources that return a maximum of around 2,000 results for a single query (Shakeel et al 2018). To customize these abstract search strings, we implemented a tool that automatically adapted the strings to each resource and its API. Moreover, our tool automatically performed the search through the APIs. We remark that we searched always with the exact same search string, meaning that even if we may have had a fault in an adaptation, the papers identified should still be the same.

Technical Limitations Due to technical limitations of existing literature resources (Shakeel et al 2018), we searched only in full texts and keywords—which we indicate with the corresponding prefixes and which most of the selected resources support for manual and API searches. However, there are further limitations that do not allow us to conduct the same searches on all resources. First, ACM does not provide an API, wherefore we cannot perform our API case studies. Second, Springer only allows full-text searches, which is why we can only employ the first search string on this literature resource.

Analysis Besides the fully automatic search performed by our tool, we also manually performed the automatic searches on the web interfaces. This was done by the second author, who executed the searches and inserted the exported results into the implemented tool. Afterwards, we automatically checked for duplicates to verify interface and temporal consistency, using digital object identifiers, if available, or the remaining bibliographic data, otherwise. Finally, we manually checked the results and verified all differences that we identified.

Time Frame We started with the fully automated analysis of our tool, to check if it behaves correctly. This process started on November 15th 2016 and we used the results to check for consistency of the APIs. We started 10 days later with the manual search on November 25th 2016 (with two additional days of testing on the ACM Digital Library), from which point forward we used all results for assessing the resources' consistencies. After this point in time, we performed all searches once a day until December 23rd 2016.

6.2 Results and Discussion

In the following, we distinguish between the results of our descriptive multi-case study that are concerned with *interface consistency* and *temporal consistency*. For each, we first report the results and afterwards discuss the implications.

Interface Consistency We show the results for the interface consistency of IEEE, Springer, and Science Direct in Figure 7, Figure 8, and Figure 9, respectively. To better illustrate the data, we split it up for each search string that we employed and we separately display the numbers of returned papers for each resource. The gray bars show the numbers of papers that we identified through both, manual and API search, on each day, represented by the number at the bottom of each bar. Thus, the gray bars indicate the consistency of both searches compared to each other.

We further show the numbers of papers that we identified solely with one of the two searches, but not the other. The second row of numbers from the bottom corresponds to the API search, illustrated with the circles (○) on top or above the gray bars. Identically, the row of numbers on top represents papers found solely through the manual search and aligns to

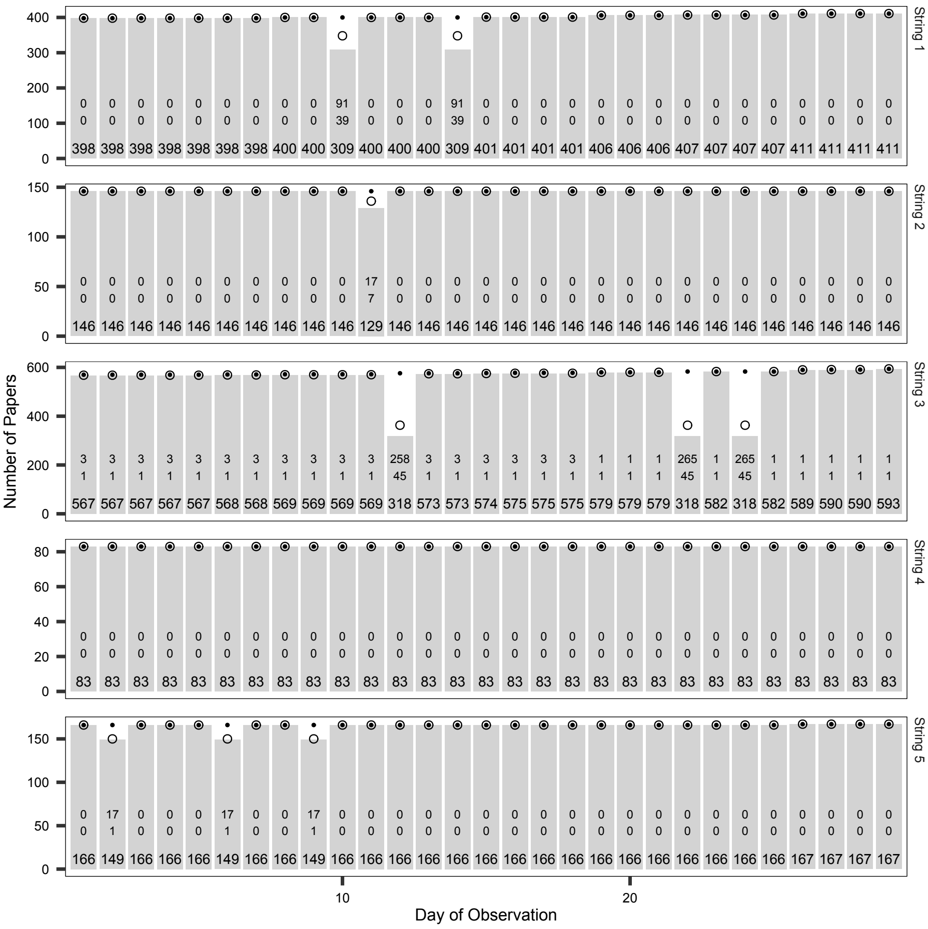

Fig. 7 Interface consistency of IEEE. From the bottom: The first row of numbers represents the papers identified by both searches (manual and API) and corresponds to the gray bars. The second row represents the papers identified only by the API search and corresponds to the circles (○). The third row represents the papers identified only by the manual search and corresponds to the dots (·).

the dots (·) in the plots. Consequently, if the dots are in the middle of the circles, and thus on top of the gray bars, there are no discrepancies between the searches, which indicates consistency of both interfaces compared to each other. In such situations, the second and third row of numbers that indicate the unique papers for each interface are zero.

Comparing the different search strings, we can see that they all return different numbers of papers. As aforementioned, we intended to have varying sample sizes to broaden our testing setup. We remark that increasing and afterwards constant numbers indicate that new papers have been added—which we expected for a period of a month.

For IEEE (cf. Figure 7), we can see that the results of our searches vary for several days of our observation. We can see that on some days the API search is incomplete compared to the manual search, returning even fewer papers than the days before and afterwards. Seeing the overall numbers of papers, the results indicate that this seems to partly align to days at which papers are added into this resource. However, for String 3, a mismatch of one to

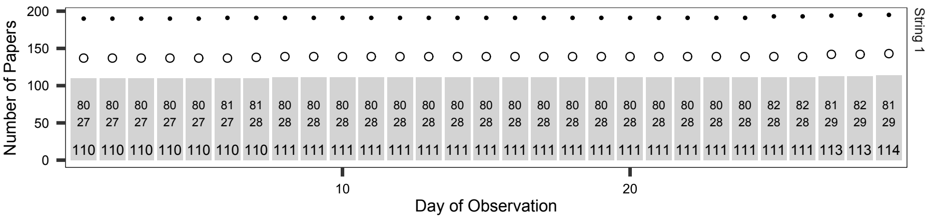

Fig. 8 Interface consistency of Springer. From the bottom: The first row of numbers represents the papers identified by both searches (manual and API) and corresponds to the gray bars. The second row represents the papers identified only by the API search and corresponds to the circles (○). The third row represents the papers identified only by the manual search and corresponds to the dots (·).

four papers persists throughout our whole observation period. We see a similar behavior for Springer (cf. Figure 8), but here it seems to be consistent. While IEEE is sometimes varying, we never obtained the same papers for Springer when comparing manual and API searches. More precisely, both searches return distinct, yet relevant sets of papers. In addition, there seems to be an update delay (see also Figure 10), as we sometimes found new papers at different days for each search. For example, at day six, we found one more paper with the manual search that was also found by the API search at day eight—at which the number of papers found by both searches increased by one, while the number for the manual search (top row) decreased by one. In contrast, for Science Direct (cf. Figure 9), we can see that all searches always returned consistent results. This is the behavior that is necessary to ensure that we can replicate a search and obtain the same results.

Discussion. The results of our descriptive multi-case study are concerning. They indicate that researchers cannot literally replicate the searches of many systematic literature reviews at any point in time. Worse, such searches are potentially incomplete if they rely solely on a search through the web interface or an API search. As most systematic literature reviews report that they only used automatic searches (without additional snowballing or other extensions, cf. Section 5.3) and do not report that they used both interfaces (or which of these), they may have missed some papers in the initial set. Thus, also some relevant papers may be missing form the included results and hide important evidence (Badampudi et al 2015; Jalali and Wohlin 2012).

Moreover, without knowing the exact tools and search interfaces that the researchers used, it is not possible to replicate a systematic literature review. For example, some tools may rely on an API, while others crawl the web interfaces of the literature resources. Thus, replicating a search is only possible if the same version of the same tool is used. Considering that we barely found this information during our tertiary study, this is a significant threat for replications of the search processes of systematic literature reviews.

Temporal Consistency In Figure 10, we show the results for the temporal consistency of the returned papers. We display for each literature resource and search string that we could employ, how many papers have been added or removed at each day of our observation. To this end, we show for each string two marks at each day, with those above zero representing additions and those below zero representing deletions. If only one, additions or deletions, or neither occurred, one mark is always at zero. We remark again that ACM does not provide an API, while we could only employ the first search string for Springer.

We can see that for the manual search of all resources only additions appeared during our whole observation. This is the expected behavior, as papers are added to literature resources

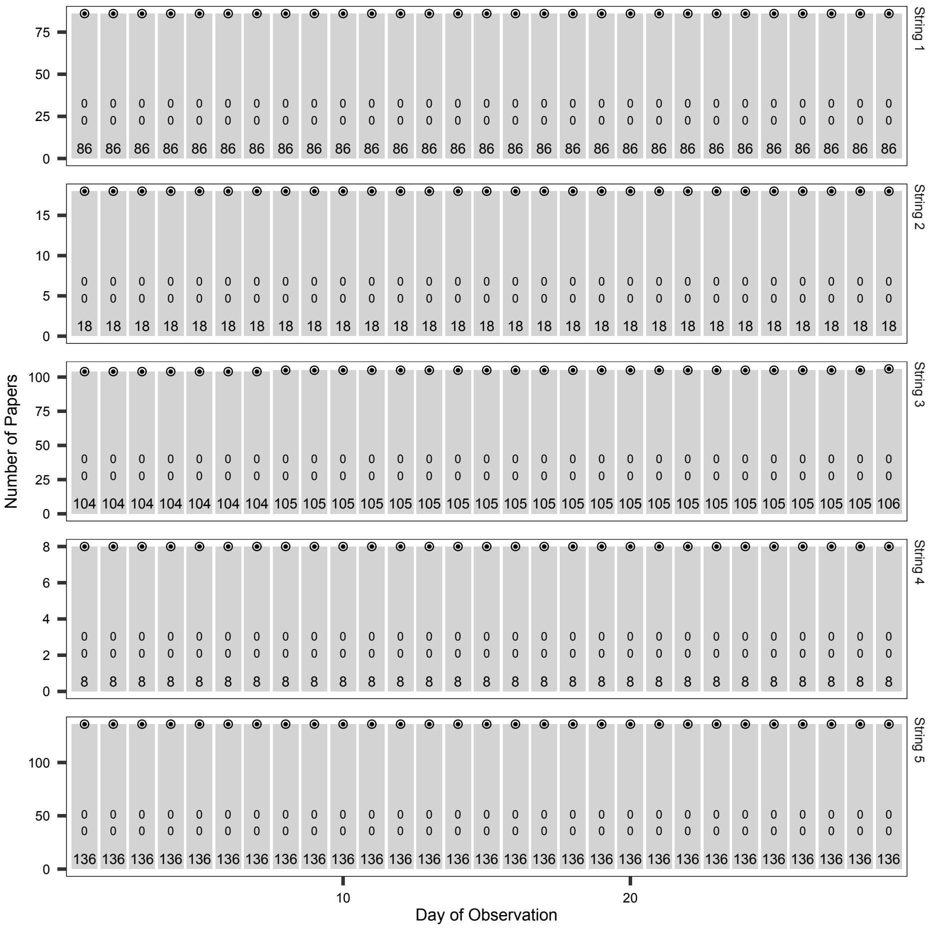

Fig. 9 Interface consistency of Science Direct. From the bottom: The first row of numbers represents the papers identified by both searches (manual and API) and corresponds to the gray bars. The second row represents the papers identified only by the API search and corresponds to the circles (○). The third row represents the papers identified only by the manual search and corresponds to the dots (·).

after publication, and thus made available to researchers. In contrast, the API searches of IEEE and Springer (once) also returned fewer papers at some point in time. For IEEE, we can see a certain pattern: The same number of papers that was removed at one day was added again the day after. For instance, at day 33, 44 papers were added, while 264 were removed for String 3. On the next day, the same papers were removed and added again, respectively. Consequently, there is no difference in the results for days 32 and 34, besides added papers. The same is true for the other occasions and while this pattern is common, it is not always aligned to an addition of papers (cf. Figure 7). It is unclear why these discrepancies occur.

Discussion. Again, the results we obtained for temporal consistency are concerning. While the manual search of each literature resource seems to be consistent (as far as our case studies are concerned), the API searches vary heavily. The most extreme case is IEEE, for which we found large changes for some days of our observation. This means that any search conducted with the API at a single day in this resource can be biased. If the search is not checked at

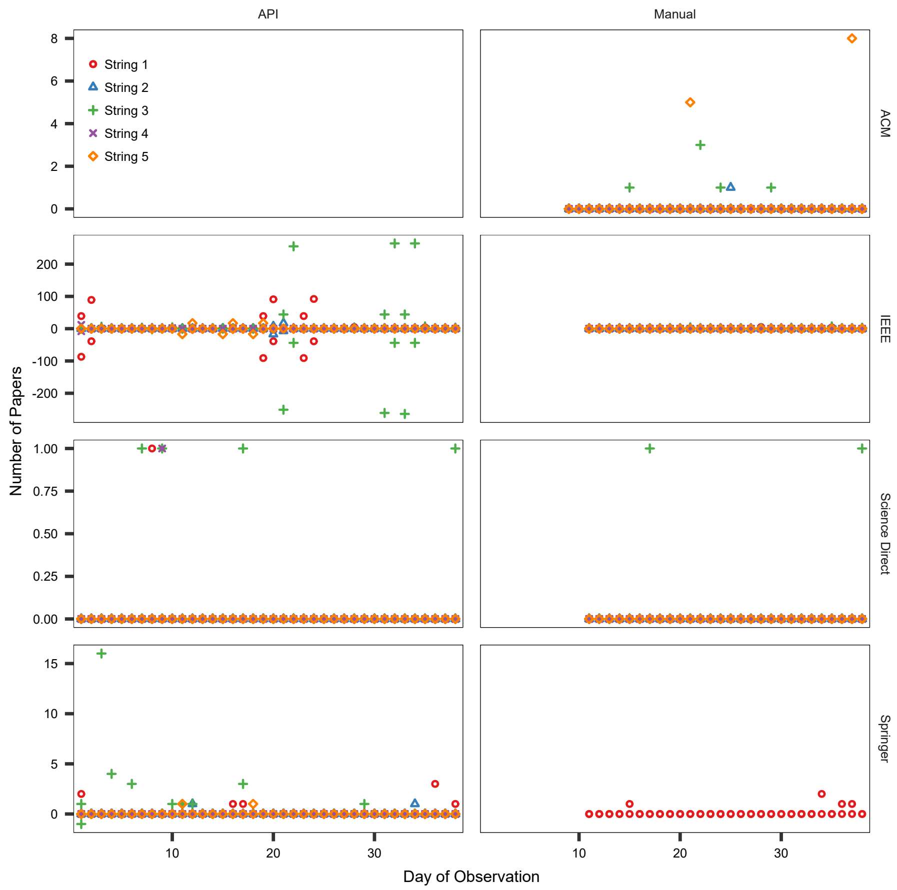

Fig. 10 Consistency of API (left) and manual searches (right) for each literature resource and search string. ACM does not provide an API, while Springer does not support the same features in both scenarios. Marks that are above zero represent added papers, while marks below zero represent removed papers. We show two marks for each observation to consider that papers may have been added and removed at the same day.

multiple days, researchers may include fewer or more papers. Moreover, researchers who replicate such a systematic literature review have to be lucky to obtain the same papers.

6.3 Threats to Validity

Internal Validity The selected search strings yield different sets of papers and may be subject to fewer or more changes, depending on the topic and publication activity. Consequently, this could be a threat to the internal validity, as we derived our findings based on only five strings. However, these strings cover different topics and intentionally return varying numbers of papers. Thus, we argue that they are representative and show several problems of the analyzed literature resources. This remains the case, even though we could not employ all search strings on all literature resources.

External Validity Overall, we only considered four literature resources. This means that we cannot conclude in general how reliable literature resources in software engineering (or computer science) are. However, we focused on established resources and the identified issues should be investigated and tested for all of them. While our selection of literature resources means that we cannot directly transfer the results, our findings are still alarming and should be a warning sign when using other literature resources.

Conclusion Validity Considering the conclusions we derived, we reported all details of our descriptive multi-case study and carefully analyzed the results. Thus, we argue that we were able to derive meaningful results that are reliable based on our findings. Still, one issue in our study may be that we wrongly identified papers as overlapping or unique, for example, due to missing or wrong data (e.g., missing DOI). To mitigate this threat, we partly verified the results manually to ensure that the matches of papers have been correct.

6.4 Summary

Overall, we can summarize our findings to answer our second research question: *To what extent can we replicate searches on literature resources?* Based on the results we obtained with our descriptive multi-case study, we found that replicating searches conducted in systematic literature reviews is problematic. Manual as well as API searches of literature resources can be biased to some extent and only Science Direct and ACM (for their web interfaces) fulfill our consistency requirements. In particular, we found the following factors that can prevent a reliable replication of searches reported in systematic literature reviews:

1. Only Science Direct seems to be interface consistent, while neither IEEE nor Springer are. We cannot conclude meaningful results for ACM, due to the missing API. In contrast, the manual search of all analyzed libraries seems to be temporally consistent. Considering the problems of available APIs, we argue that using them or tools that are based on these threatens the ability of researchers to replicate the search process of systematic literature reviews. Moreover, additional information needs to be reported, in particular, on repeating and verifying searches on several days.
2. The API searches partly allow different options to define search strings compared to the web interfaces. As the researchers who conducted the systematic literature reviews we analyzed report that they used different tools (most are not reporting any information in this regard), this discrepancy threatens replications.

We considered four of the most widely-used literature resources in computer science and conclude that it is hardly possible to replicate automatic searches of systematic literature reviews. This is mostly due to misbehavior of some of the resources, which results in some papers potentially missing in the conducted systematic literature reviews. We refer to this situation as *searching threat*, which researchers themselves cannot fully overcome, but address by providing additional information, repeating their searches, and combining search strategies. Arguably, researchers could rely only on those resources that are consistent, which should mean they are deterministic. However, we found problems in established resources that should not be ignored and it seems necessary for the providers to check and prove that their resources work properly.

7 Conclusions

In this article, we reported the details of an extensive tertiary study and a descriptive multi-case study. Within both, we have been concerned with the ability to replicate the searches of systematic literature reviews. While our results show that most researchers report the information that is requested by common guidelines and should *ideally* be enough to replicate a systematic literature review, we identified several issues that are connected to **reporting (R)** and **searching (S)** threats, as discussed in Section 5 and Section 6, respectively. We also identified one **additional (A)** threat that we experienced during our study:

- R_1 Not all systematic literature reviews report that they used a guideline and it is unclear, what differences between guidelines have what impact.
- R_2 Many papers may omit information that is relevant for replications, which can be due to unawareness of existing issues or space limitations.
- R_3 Researchers cannot employ search strings the same way to all literature resources, wherefore all adapted versions should be reported.
- R_4 Many researchers seem to be unaware of searching and reporting threats to systematic literature reviews, which they should describe.
- S_1 A sole automatic API search seems unreliable, wherefore researchers should include a larger set of resources (including summarizing ones, such as DBLP or Google Scholar) and also an additional manual and/or snowballing phase.
- S_2 While the development of systematic literature review tools is an important research direction (Hassler et al 2016), it seems necessary to first analyze the problems of literature resources further to implement repeatable search processes.
- S/R_1 Literature resources have several limitations concerning the consistency of their API searches. Researchers have to be aware of these issues and have to report exactly how they searched for papers. Thus, we recommend to employ API searches at multiple days to check the consistency of the returned results.
- A/S_1 We found that using search strings with different encodings, for instance, manual input and copied from different PDF readers, can break the searches of literature resources. In particular, we tested this for the four resources we analyzed in our descriptive multi-case study. Overall, IEEE as well as Springer are vulnerable to this issue: Different encodings in the search string may yield varying results with only a small overlap, while all returned papers are relevant. Thus, both resources provide incomplete results if not all encodings are tested.

Overall, we identified several reporting and searching threats that challenge the replication of the search process of a systematic literature review. While some of the reporting threats, for instance, missing details on the search string (R_2) and its adaptations (R_3), already pose significant problems in verifying and replicating a search strategy, they can become even worse in combination with searching threats. For example, if we only know of a single search string for an automated search (R_3), but not how the researchers employed it (S/R_1), several methodological variations are possible. In this case, it would be necessary that we adapt the search string ourselves to perform a replication, without being able to check whether the original study has been correct in this regard. Even then, we do not know whether we should use the web interface, an API, or a certain tool to execute the queries. Thus, the threats to validity and replications of systematic literature reviews may multiply, due to the dependencies between these threats.

Particularly important is researchers' awareness for such threats, when we put our findings into the context of related work (cf. Section 3). Several researchers highlighted the importance of replications, but our findings suggest that these are hampered significantly. Multiple, partly contradicting, studies investigated to what extent a different set of papers and search strategies may result in biased conclusions. Due to the different results, it may be best to summarize that missing papers can result in biases, and thus the ability to understand and replicate searches is important. Similar to us, other studies suggest an improvement in the details that are reported for a systematic literature review. Still, we see that some of the threats we identified may be known by experts, but rarely by novices, and that additional information is necessary to assess to what extent we can address these threats.

Considering our findings, we can answer the question of our title, whether we can replicate the searches of systematic literature reviews with no. Overcoming the identified threats is not only in the hands of researches, but also publishers and maintainers of literature resources. Still, researchers who conduct, review, read, and replicate systematic literature reviews should be aware of the identified threats. Researchers can address these threats to some extent by providing additional information and extending their searches.

In future work, we see the need for more empirical studies on literature resources and their issues. For example, it would be helpful to explain the patterns we found for IEEE. In the same direction, interviews and communication with developers and maintainers of literature resources could help to understand reasons for the inconsistencies we found. Based on this, we could derive more precise recommendations for researchers on how to search in specific resources or may be able to provide an interface that allows for consistent searching. Moreover, developing tools to support and improve systematic literature reviews is a major issue that has to be addressed. We remark that we did not perform a sensitivity analysis in this article, meaning that we did not investigate to what extent the discrepancies we identified would actually change the outcome of a systematic literature review, which is important future work. Finally, while systematic literature reviews are a valuable research method, we as computer scientists seem to have few to no reliable search opportunities or interfaces and important questions are, whether we should rely on them at this point in time and why we seem to have these problems?

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Appendix – List of Reviewed Publications

Authors	Title	Year
Cruz-Hinojosa, N. J.; Gutiérrez-De-Mesa, J. A.	Literature review of the situation research faces in the application of ITIL in Small and Medium Enterprises	2016
Khosravi, P.; Rezvani, A.; Wiewiora, A.	The impact of technology on older adults' social isolation	2016
Dikert, K.; Paasivaara, M.; Lassenius, C.	Challenges and success factors for large-scale agile transformations: A systematic literature review	2016
Jafari Navimipour, N.; Charband, Y.	Knowledge sharing mechanisms and techniques in project teams: Literature review, classification, and current trends	2016
Milani, A. S.; Navimipour, N. J.	Load balancing mechanisms and techniques in the cloud environments: Systematic literature review and future trends	2016
Idri, A.; Hosni, M.; Abran, A.	Systematic literature review of ensemble effort estimation	2016
Zare, M.; Pahl, C.; Rahnama, H.; Nilashi, M.; Mardani, A.; Ibrahim, O.; Ahmadi, H.	Multi-criteria decision making approach in E-learning: A systematic review and classification	2016
Costa, E.; Soares, A. L.; De Sousa, J. P.	Information, knowledge and collaboration management in the internationalisation of SMEs: A systematic literature review	2016
Melendez, K.; Dávila, A.; Pessoa, M.	Information technology service management models applied to medium and small organizations: A systematic literature review	2016
Soltani, Z.; Navimipour, N. J.	Customer relationship management mechanisms: A systematic review of the state of the art literature and recommendations for future research	2016
Garousi, V.; Mäntylä, M. V.	When and what to automate in software testing? A multi-vocal literature review	2016
Sánchez Guinea, A.; Nain, G.; Le Traon, Y.	A systematic review on the engineering of software for ubiquitous systems	2016
Tarhan, A.; Turetken, O.; Reijers, H. A.	Business process maturity models: A systematic literature review	2016
Ali, S.; Khan, S. U.	Software outsourcing partnership model: An evaluation framework for vendor organizations	2016
Martins, L. E. G.; Gorschek, T.	Requirements engineering for safety-critical systems: A systematic literature review	2016
Balaid, A.; Abd Rozan, M. Z.; Hikmi, S. N.; Memon, J.	Knowledge maps: A systematic literature review and directions for future research	2016
Bissi, W.; Serra Seca Neto, A. G.; Emer, M. C. F. P.	The effects of test driven development on internal quality, external quality and productivity: A systematic review	2016
McGill, M. M.; Decker, A.; Settle, A.	Undergraduate students' perceptions of the impact of pre-college computing activities on choices of major	2016
de França, B. B. N.; Travassos, G. H.	Experimentation with dynamic simulation models in software engineering: planning and reporting guidelines	2016
Sajid, A.; Abbas, H.	Data privacy in cloud-assisted healthcare systems: State of the art and future challenges	2016
Souza, D. M.; Felizardo, K. R.; Barbosa, E. F.	A systematic literature review of assessment tools for programming assignments	2016
Anuar, U.; Ahmad, S.; Emran, N. A.	A simplified systematic literature review: Improving Software Requirements Specification quality with boilerplates	2016
Gheni, A. Y.; Jabar, M. A.; Jusoh, Y. Y.; Mohd Ali, N.; Abdullah, R. H.	Factors for communication technologies selection within virtual software teams	2016
Jia, J.; Zhang, P.; Capretz, L. F.	Environmental factors influencing individual decisionmaking behavior in software projects: A systematic literature review	2016
Muccini, H.; Sharaf, M.; Weyns, D.	Self-adaptation for cyber-physical systems: A systematic literature review	2016
Yaseen, M.; Baseer, S.; Ali, S.; Khan, S. U.; Abdullah	Requirement implementation model (RIM) in the context of global software development	2016
Batool, D. -. -.; Molta, Y. H.; Sarwar, A.; Abbasi, M. A.; Jabeen, J.	Software architecture and requirements: A systematic literature review	2016
Luh, R.; Marschalek, S.; Kaiser, M.; Janicke, H.; Schrittwieser, S.	Semantics-aware detection of targeted attacks: a survey	2016
Spanos, G.; Angelis, L.	The impact of information security events to the stock market: A systematic literature review	2016
Soomro, A. B.; Salleh, N.; Mendes, E.; Grundy, J.; Burch, G.; Nordin, A.	The effect of software engineers' personality traits on team climate and performance: A Systematic Literature Review	2016
Tahir, T.; Rasool, G.; Gencel, C.	A systematic literature review on software measurement programs	2016
Farwick, M.; Schweda, C. M.; Breu, R.; Hanschke, I.	A situational method for semi-automated Enterprise Architecture Documentation	2016
Schatz, D.; Bashroush, R.	Economic valuation for information security investment: A systematic literature review	2016
Kekgathetse, M. B.; Letsholo, K. J.	A survey on database synchronization algorithms for mobile device	2016
Lu, Q.; Zhu, L.; Zhang, H.; Wu, D.; Li, Z.; Xu, X.	MapReduce job optimization: A mapping study	2016
Aris, H.	Sustainable solvers participation in non-profit mobile crowdsourcing initiatives: A review of successful applications	2016
Marçal, I.; Garcia, R. E.; Eler, D. M.; Junior, C. O.; Correia, R. C. M.	Techniques for the identification of crosscutting concerns: A systematic literature review	2016
Da Silva, G. C.; De Figueiredo Carneiro, G.	Software process improvement in small and medium enterprises: A systematic literature review	2016
Li, Z.; Zhang, H.; O'Brien, L.; Jiang, S.; Zhou, Y.; Kihl, M.; Ranjan, R.	Spot pricing in the cloud ecosystem: A comparative investigation	2016
Ali, O.; Soar, J.; Yong, J.	An investigation of the challenges and issues influencing the adoption of cloud computing in Australian regional municipal governments	2016
Qu, M.; Yu, S.; Chen, D.; Chu, J.; Tian, B.	State-of-the-art of design, evaluation, and operation methodologies in product service systems	2016
Soomro, Z. A.; Shah, M. H.; Ahmed, J.	Information security management needs more holistic approach: A literature review	2016
Hassan, M.; Jabar, M. A.; Sidi, F.; Jusoh, Y. Y.; Hassan, S.	Enterprise resource planning adoption lifecycle: A systematic literature review	2016
Hakami, Y. A. A.; Hussei, A. R. C. B.; Adenuga, K. I.	Preliminary model for computer based assessment acceptance in developing countries	2016
Rasti, Z.; Darajeh, A.; Khayami, R.; Sanatnama, H.	Systematic literature review in the area of Enterprise architecture during past 10 years	2016
Oliveira, J. B.; Lima, R. S.; Montevechi, J. A. B.	Perspectives and relationships in supply chain simulation: A systematic literature review	2016
Torrecilla-Salinas, C. J.; Sedeño, J.; Escalona, M. J.; Mejías , M.	Agile, web engineering and capability maturity model integration: A systematic literature review	2016
Gasparic, M.; Janes, A.	What recommendation systems for software engineering recommend: A systematic literature review	2016
Boyle, E. A.; Hainey, T.; Connolly, T. M.; Gray, G.; Earp, J.; Ott, M.; Lim, T.; Ninaus, M.; Ribeiro, C.; Pereira, J.	An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games	2016
Sobernig, S.; Hoisl, B.; Strembeck, M.	Extracting reusable design decisions for UML-based domain-specific languages: A multi-method study	2016
Chen, T.	Technology-supported peer feedback in ESL/EFL writing classes: a research synthesis	2016
Al-Zubidy, A.; Carver, J. C.; Heckman, S.; Sherriff, M.	A (updated) review of empiricism at the SIGCSE technical symposium	2016
Decker, A.; McGill, M. M.; Settle, A.	Towards a common framework for evaluating computing outreach activities	2016
Charband, Y.; Jafari Navimipour, N.	Online knowledge sharing mechanisms: A systematic review of the state of the art literature and recommendations for future research	2016

Authors	Title	Year
Smuts, H.; Kotze, P.; Van Der Merwe, A.; Loock, M.	Threats and opportunities for information systems outsourcing	2016
Banaeianjahromi, N.; Smolander, K.	What do we know about the role of enterprise architecture in enterprise integration? A systematic mapping study	2016
Effing, R.; Spil, T. A. M.	The social strategy cone: Towards a framework for evaluating social media strategies	2016
Elbattah, M.; Roushdy, M.; Aref, M.; Salem, A. -. M.	Large-scale ontology storage and query using graph database-oriented approach: The case of Freebase	2016
Yaseen, M.; Baseer, S.; Sherin, S.	Critical challenges for requirement implementation in context of global software development: A systematic literature review	2016
Szvetits, M.; Zdun, U.	Systematic literature review of the objectives, techniques, kinds, and architectures of models at runtime	2016
Thuan, N. H.; Antunes, P.; Johnstone, D.	Factors influencing the decision to crowdsource: A systematic literature review	2016
Najafabadi, M. K.; Mahrin, M. N.	A systematic literature review on the state of research and practice of collaborative filtering technique and implicit feedback	2016
Caron, X.; Bosua, R.; Maynard, S. B.; Ahmad, A.	The internet of things (IoT) and its impact on individual privacy: An Australian perspective	2016
Isern, D.; Moreno, A.	A systematic literature review of agents applied in healthcare	2016
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