The Effects of Continuous Integration on Software Development: a Systematic Literature Review

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Abstract Context: Continuous integration (CI) is a software engineering technique that proclaims a set of frequent activities to assure the health of the software product. Researchers and practitioners mention several benefits related to CI. However, no systematic study surveys state of the art regarding such benefits or cons. Objective: This study aims to identify and interpret empirical evidence regarding how CI impacts software development. Method: Through a Systematic Literature Review, we search for studies in six digital libraries. Starting from 479 studies, we select 101 empirical studies that evaluate CI for any software development activity (e.g., testing). We thoroughly read and extract information regarding (i) CI environment, (ii) findings related to effects of CI, and (iii) the employed methodology. We apply a thematic synthesis to group and summarize the findings. Results: Existing research has explored the positive effects of CI, such as better cooperation, or negative effects, such as adding technical and process challenges. From our thematic synthesis, we identify six themes: development activities, software process, quality assurance, integration patterns, issues & defects, and build patterns. Conclusions: Empirical research in CI has been increasing over recent years. We found that much of the existing research reveals that CI brings positive effects to the software development phenomena. However, CI may also
bring technical challenges to software development teams. Despite the overall positive outlook regarding CI, we still find room for improvements in the existing empirical research that evaluates the effects of CI.

**Keywords** Continuous integration · impact · adoption · software development

1 Introduction

Continuous integration (CI) is a software engineering practice that became increasingly popular with the eXtreme Programming methodology, which was proposed by Kent B. [1] in the late 90s. CI, as a practice, proposes the usage of a set of sub-practices that are synergic, e.g., frequent code commits, automated tests, frequent builds, immediately fixing a broken build, among others [11][17]. As CI gained popularity, several benefits related to CI were proclaimed, such as risks reduction, decrease in repetitive manual processes, improvement of project visibility, greater confidence in the software product, easiness to locate and fix bugs, among others [17] [11].

Given the increasing popularity of CI along with its claimed benefits, there have been substantial research efforts related to CI. Researchers have investigated CI practices [29] [38][43], environments & tools [22][37][44], potential benefits, [2][15][35], potential problems [8][20][30][39], and even new practices [27][32][42] in diverse settings. Given these valuable and recent research contributions, our community is in need of a clear map of the empirical benefits or cons of adopting CI. Existing research has summarized the findings in literature with respect to (i) agile methods [10] and (ii) continuous integration, delivery and deployment [25][33][35]. However, what is missing is a systematic study which covers and summarizes all the potential benefits and cons regarding CI (i.e., the effects of adopting CI on the development process).

Therefore, in this work, we investigate: (i) how CI has been evaluated by existing research—and which results were found; (ii) the criteria used to identify whether a given project uses CI or not—which is important for designing empirical studies related to CI; and (iii) which research methodologies were used in the existing studies that evaluate the effects of adopting CI. Our work is a *Systematic Literature Review* (SLR) [23] of the existing empirical evidence regarding the effects of CI on the software development phenomena. As such, we expect to draw a picture of the reported benefits and cons of adopting CI, providing meaningful and relevant evidence-based insights to practitioners and researchers—which can potentially help organizational plans or further academic endeavors. Given the goal of our SLR, we investigate the following research questions:

– **RQ1.** What are the existing criteria to identify whether a software project uses CI?
– **RQ2.** What are the reported claims regarding the effects of CI on software development?
– **RQ3.** Which empirical methods, projects and artifacts are used in the studies that investigate the effects of CI on software development?

In total, we find 479 papers, from which, based on our criteria, we select 101 papers. Afterwards, we perform a full review of the 101 selected papers. First, we summarize the main criteria that are used to identify whether a given project uses CI or not. Next, through thematic analysis, we analyze the claims regarding the benefits and challenges of adopting CI, which we find in 38 of the 101 papers. In this analysis, the authors codify such claims and organize them in themes. Then, we catalog and discuss the methodologies used in these papers.
From our thematic analysis, we identify six themes that are covered in the existing literature: development activities, software process, quality assurance, integration patterns, issues & defects, and build patterns. Existing research has explored the effects of CI on these six themes, especially development activities and software process, which are the most frequent themes.

The remainder of this paper is organized as follows: Section 2 provides the background regarding continuous integration and investigate related SLRs. In Section 3 we describe our study. We present the quantitative and qualitative results of the research questions in Section 4. In Section 5, we discuss our main findings and provide research insights. We discuss the threats to validity in Section 6 and we draw conclusions and future directions in Section 7.

2 Background and related work

In this section, we provide the background material regarding CI (section 2.1) and discuss the existing systematic literature reviews that are related to our work (section 2.2).

2.1 Continuous Integration

Continuous Integration (CI) is one of the eXtreme Programming (XP) methodology proposed by Kent Beck [1]. The overarching goal of CI is to reduce the cost of integrating the code developed by different developers in a team (or different teams) by making integration a daily practice. For example, there must be no more than a couple of hours between code integration. While CI compels the code to be collective and the knowledge to be shared more, CI’s main benefit is the reduced risk of a big and cumbersome integration (e.g., after days, weeks, or months of work developed) [1].

To properly employ CI, at least four mechanisms are required: (i) a version control system, (ii) a build script, (iii) a feedback mechanism, and (iv) a process for integrating the source code changes [11]. Modern distributed version control systems (VCS), especially those based on Git, have grown in popularity because of social coding platforms, such as GitHub [40], which have fostered collaborative software development. Within these popular social coding platforms, several services have been proposed to support CI (e.g., TravisCI, CircleCI and Jenkins), easing the automation of build pipelines, which are triggered by source code changes on the VCS [21].

Duvall PM et al. [11] advocate that CI is the centerpiece of software development, ensuring the health and determining the quality of software. To get the benefits of CI, the authors argue that developers should implement all of its practices on a daily basis, whereas implementing only a fraction of the practices is not enough to employ CI. Fowler, in his definition of CI, also mentions a series of critical practices to make CI effective [17].

2.1.1 Continuous Integration Practices

Table 1 shows an overview of the practices proposed by Duvall PM et al. [11] in relation to the practices reported by Fowler [17]. The practices proposed by Duvall are shown in the second column, while the practices reported by Fowler are shown in the third column. In the first column, we organize the CI practices into four groups: (i) integration, (ii) test, (iii) build, and (iv) feedback.
“Commit code frequently” is the practice of integrating code changes as “early and often” as possible to a “single source code repository” (e.g., GitHub, GitLab, or Bitbucket). This practice is central to CI because it prevents a complex integration—an integration that requires more time and effort—while treating potential integrations problems [11, 17].

When it comes to testing, CI bears the principle that “all tests and inspections must pass”. This practice advocates that not only tests must pass but also the inspections related to coding and design standards (e.g. test coverage, cyclomatic complexity, or others). Ideally, the tests and inspections should be triggered in an automated fashion. Therefore, CI requires developers to “write automated development tests”, “making the builds to become self-testing”, which enables a fully automated build process that provides meaningful feedback [11, 17].

Still regarding tests, Fowler recommends to “test the software in a clone of the production environment” to mitigate the risk of not identifying problems that would occur only within the production environment. For this reason, Fowler also proposes the “automated deployment”—to prepare test-environments automatically—and the practice of “making it easy for anyone to get the latest executable”—so that anyone has easy access to the current state of development [17].

With respect to build practices, the team must follow the “don’t commit broken code” practice. To do so, it is vital to employ the “automate the build” practice. The build automation consists of empowering the team with scripts that fully manage the build process, from dependency managers (e.g., Maven, Gradle, NUGET, or Bundler) and tests to database schema, or other required tool. Once a consistent build script is set, developers should “run private builds” that emulate an integration build in their workstation, ensuring a well-succeeded build process before integrating their changes into the central repository (i.e., the mainline) [11, 17].

Additionally, Fowler recommends that “every commit should build the mainline on an integration machine”, i.e., a change sent to the mainline repository must trigger a build process in a dedicated server. It is also important to “keep the build fast”, so the dedicated server can be effective to give rapid feedback, helping developers to “fix broken builds immediately”. Regarding build duration, the eXtreme Programming (XP) recommends the limit of 10 minutes. Builds that take more than 10 minutes may lead the development team to give up on using CI [11, 17].
“Fix broken builds immediately” is cited both by Fowler and Duvall PM et al. A build may break due to a compilation error, a failed test, or several other reasons. When a build is broken, the development team must focus on fixing the build before any other implementation activity—the build should be always on green.

There is also CI practices related to feedback. One example is the practice “everyone can see what’s happening”, which makes the communication clear and transparent within or across development teams. The immediate feedback from CI allows the development team to “avoid getting broken code”. In other words, a developer can check the current build status before performing a checkout (or pull)

2.2 Related Work

In this section, we discuss Systematic Literature Reviews (SLR) that are related to our work. We highlight the main differences in contributions and findings of five others SLRs, as shown in Table 2. In particular, Dikert K et al. studied agile methods [10]. Laukkanen E et al. studied continuous delivery [25]. Shahin et al. studied continuous integration, delivery and deployment [33]. Two other studies by Ståhl D and Bosch J investigated the existing literature regarding CI [35,36].

Ståhl and Bosh [35] investigated which known benefits of CI are experienced in the industry. They conducted a systematic literature review, including 33 articles with 7 explicit claims regarding the benefits of CI. To complement the study, they interviewed 22 individuals (developers, testers, project managers and line managers) from 4 projects. Their results reveal high standard deviations in answers, indicating disparate reported experiences. Differently from our study, Ståhl and Bosh [35] do not present an exhaustive list of CI benefits nor explore the potential negative effects (or challenges) of adopting CI.

Another study by Ståhl and Bosh [36], motivated by their previous work, performed a literature review on CI to better understand the different benefits of CI adoption. The new study included 46 articles to find differing practices, supporting the identification of potential CI variation points. They synthesized the extracted statements in 22 clusters, of which only six do not have disagreements. In addition, the study proposes a descriptive model for documenting these variations and highlights the need for better documenting such CI variants to understand any benefit or disadvantage of them better. Therefore, differently from our work, Ståhl and Bosh do not discuss the pros and cons of CI that are reported in existing literature.

Dikert et al. [10], conducted an SLR on large-scale agile transformations (i.e., changes in practices or organizational culture in companies with 50 or more people, or at least six teams) to identify success and challenge factors. They searched for papers describing industrial cases in agile development adoption, including 52 publications in a thematic synthesis. The authors documented 35 challenges in 9 categories, and 29 success factors distributed into 11 categories. The study focuses on a more general perspective of agile methods adoption and does not touch the success and challenges factors of CI adoption directly.

Shahin et al. [33] studied 69 papers in a SLR to classify approaches/tools and to identify challenges and practices in Continuous Integration, Continuous Delivery, and Continuous Deployment. The contributions of the study include the classification of approaches/tools, a list of critical factors to implement continuous practices, a guide to select approaches/tools, and a list of research directions.

Laukkanen et al. [25], also performed a SLR to explore the reported problems when adopting Continuous Delivery. Their study also identified causes and solutions to these prob-
lems. The study selected 30 articles in which they found 40 problems and 29 solutions. The problems and solutions were classified into seven themes, e.g., integration, testing, and build design.

Differently from the above mentioned studies, our SLR analyzes a substantially larger amount of articles, i.e., 101 studies ranging from the years of 2003 to 2019, both exploring the positive and negative effects of CI. Considering the years of the related works presented it is noticeable that the newest (i.e. Laukkanen et al. [25] and Shahin and colleagues [33]) are dated to the year 2017, including primary studies at most the year of 2016 [33]. Therefore our work contributes to the community by advancing at least three years in the related literature. Our study also innovates not only by studying the effects of CI but also by considering the specific CI practices present in different CI settings. Moreover, our work also analyzes the methodologies employed in our 101 studies.

Table 2  Systematic Literature Reviews (SLRs) that related to our work. We show the authors, focus, findings, number of included articles, and the year of publication.

| Study                      | Focus                        | Findings                                           | # Papers | Year |
|----------------------------|------------------------------|----------------------------------------------------|----------|------|
| Stål and Bosh [35]         | Continuous integration       | Benefits of CI                                     | 33       | 2013 |
| Stål and Bosh [36]         | Continuous integration       | Differences in CI practices                        | 46       | 2014 |
| Dikert et al. [10]         | Large-scale agile transformations | Challenges and success of agile adoption        | 52       | 2016 |
| Shahin et al. [33]         | Continuous integration, delivery, and deployment | Approaches, tools, challenges and practices | 69       | 2017 |
| Laukkanen et al. [25]      | Continuous delivery          | Problems, causes and solutions.                   | 30       | 2017 |

3 Research Method

The main goal of our study is to identify and analyze the existing scientific evidence regarding how CI can influence the software development phenomena (both in terms of potential benefits and cons). Therefore, we perform a Systematic Literature Review (SLR) of studies that investigated the effects of CI on software development. To evaluate the scientific rigour of our target studies, we investigate the methodologies that were employed in these studies. The purpose of this investigation is to better understand the strength of the existing scientific claims regarding the effects of adopting CI. We also pay attention to how our target studies determined whether their subject projects used CI or not. Identifying whether a project uses CI is a crucial step in any study evaluating the effects of adopting CI, since this is how comparisons such as CI vs non-CI can be performed. To conduct our SLR, we follow the guidelines provided by Kitchenham and Charters [23].

The next subsections describes our review protocol [23]. Section 3.1 describes the rationale behind our research questions. Section 3.2 details the search mechanisms that we perform. Section 3.3 describes the inclusion and exclusion criteria, and the screening process. Section 3.4 describes the data extraction details, while Section 3.5 reveals the procedures that we use to synthesize the collected data. Finally, Section 3.6 explains how we assess the quality of the studies.
3.1 Research questions

To fulfill the goal of our study, we address the following research questions (RQs):

**RQ1: What are the existing criteria to identify whether a software project uses CI?**

**Rationale.** Existing research has listed a set of practices or principles related to CI [11, 19]. Some of these practices include: “commit code frequently”, “test automation”, “run private builds”, “all tests and inspections must pass”, and “fix broken builds immediately”. However, there exists evidence that many CI projects do not adopt many of these practices. For example, Felidré et al. [16] analyzed 1,270 open-source projects using TRAVIS CI (the most used CI server). They observed that about 60% of the projects do not follow proper CI practices. For example, some of the projects have infrequent commits, low test coverage, and 85% of projects take more than four days to fix certain builds. Therefore, in RQ1, we investigate which criteria have been applied in the studies to identify whether the subject projects employ CI or not. This investigation is important because it has a direct impact on the quality of the data. For example, if a project is deemed to be using CI, but perform infrequent commits and take a long time to fix builds, the empirical results observed to such a project would not be reflective of a proper CI usage.

**RQ2: What are the reported claims regarding the effects of CI on software development?**

**Rationale.** Most of practitioners adopt CI practices with the expectation of increasing the quality of software development [26]. Researchers have reported the benefits of applying CI [11, 17], such as risk reduction, decrease in repetitive manual processes, readily deployable software, improved project visibility, greater confidence in the software product, and easiness to locate and remove defects.

To help practitioners and researchers, from an evidence-based software engineering effort [24], this RQ aims to collect, organize, and compare the empirical investigations related to CI that were performed by existing studies, while highlighting the assumptions and claims associated with these empirical investigations.

**RQ3: Which empirical methods, projects and artifacts are used in the studies that investigate the effects of CI on software development?**

**Rationale.** As observed by Easterbrook S et al. [14], there is a lack of guidance regarding which methods to apply in Empirical Software Engineering (ESE) studies—which leads many researchers to select an inappropriate methodology. Rodríguez-Pérez et al. [28] investigated the reproducibility aspects of ESE through a case study. According to their investigations, 39% of the papers that were analyzed did not provide sufficient data or documentation to support the reproduction of the studies. To better understand the methodologies that are applied in the ESE field with respect to CI, in this RQ, we shed light on the methods, evaluations, domains, and kind of projects that are investigated in our target studies.

3.2 Search strategy

The search process of our SLR consists of the first six steps shown in Figure 1. Step 1—Definition of the search string (section 3.2.1), Step 2—Delimitation of the search mechanisms (section 3.2.2), Steps 3 to 6—Papers screening (section 3.3.2).

**Search String.** For our search string, we define a string to fetch papers containing the term “continuous integration” along with a word that expresses “impact” or “effect” in the title, abstract or keywords (e.g., we use words such as “impact”, “influence”, “evaluation”, etc.).
Fig. 1 Research methodology. Step 1: Search string definition; Step 2: Data search; Step 3: Duplicates removal; Step 4: Study selection; Step 5: snowballing; Step 6: snowballing study selection; Step 7: Data extraction; Step 8: Disagreements resolution; Step 9: Database import; Step 10: Thematic synthesis.

Table 3 The digital libraries included in our search along with the number of matches (before and after removing duplicates).

| Database         | # of matches | %   | # without duplicates | %   |
|------------------|--------------|-----|-----------------------|-----|
| IEEE Xplore      | 169          | 22.27 | 130                   | 27.14 |
| ACM Digital Library | 121         | 15.94 | 117                   | 27.14 |
| SpringerLink     | 53           | 6.98  | 53                    | 24.43 |
| Wiley Online Library | 4          | 0.53  | 4                     | 0.84  |
| ScienceDirect    | 12           | 1.58  | 12                    | 2.51  |
| SCOPUS           | 400          | 52.70 | 163                   | 34.03 |
| **Total**        | **759**      | **52.70** | **479**               |       |

**TITLE-ABS-KEY** (“continuous integration” AND (“impact” OR “outcome” OR “evaluation” OR “effect” OR “relationship” OR “influence” OR “importance” OR “consequence” OR “study”))

**Data Search.** Regarding the selection of digital libraries, we considered Chen et al.’s recommendations. Therefore, we included the main publishers’ sites and one index engine. Table 3 shows the amount of papers that we retrieved for each digital library. We apply the search string in each digital library separately and store the results in spreadsheets. As a result, our first search (i.e., Step 2 in Figure 1) retrieved 759 papers.
3.3 Study Selection

After performing the first search, we proceed with the study selection step. In this section, we present our selection criteria (Section 3.3.1) and the process of paper screening (Section 3.3.2).

3.3.1 Selection Criteria

In this step, we apply inclusion and exclusion criteria based on our RQs. This is an important step to aim for relevant papers from the digital libraries that we use. We adopt our inclusion and exclusion criteria in steps 3, 4, 5, and 6 (see Figure 1).

Our inclusion criteria are the following: (i) the studies must be empirical primary studies; (ii) be peer-reviewed papers; and (iii) show that CI adoption may (or may not) have an effect on any aspect of software development. Our exclusion criteria are the following: (i) the studies must not be duplicated papers; (ii) papers that do not investigate the effects of CI, but instead propose a new tool or a new practice for CI; (iii) papers that are not written in English;

3.3.2 Screening of papers

Figure 1 shows an overview of our screening steps. In Steps 1 and 2, we apply our search string (Section 3.2) onto the referred digital libraries, obtaining 759 papers. By applying the exclusion criteria in Step 3, we obtain 479 distinct papers (see Table 3).

In Step 4, we perform a reading of the 479 papers. Two authors read the title and abstract of each study and judge them based on the inclusion and exclusion criteria. By using the Cohen Kappa statistic [5], we obtain a score of 0.72, which represents a substantial agreement. Afterwards, a third author check the disagreements (there exist 34 disagreements) and resolve each one of them. As a result, a total of 79 papers was obtained at the end of Step 4.

In the next step (Step 5 in Fig. 1), we perform a backward snowballing, collecting 80 references of the selected studies, which contain the term “continuous integration”—both in the title or abstract. Next, in Step 6, two authors read the title and abstract and apply the inclusion and exclusion criteria. At this stage, we include 22 additional papers. We achieve an agreement rate of 0.76 (Cohen Kappa), signaling a substantial agreement between authors. After disagreements were resolved by a third author, we had 101 studies at the end of Step 6.

Appendix A lists the selected papers. The files containing the lists of papers on each step are available in our digital repository. A backup of the relational database that we use in our SLR is also available [34].
3.4 Data Extraction

The extraction process consists of three steps: meta-data retrieval, data extraction, and disagreement resolution. An automated process retrieves the meta-data, which includes the title, authors, year, and publication venue of the studies. We use a reference management tool named Mendeley\(^1\) to support the meta-data extraction. Mendeley exports the meta-data in an XML format. We then use a script to read Mendeley’s XML files and store the meta-data into our database.

Two authors perform the data extraction by reading all 101 studies while collecting relevant data (Step 7 in Figure 1). When a paper is completely read by each author, they both submit a form containing the data extracted from that paper. For this purpose, we use a web form containing the fields that are shown in Table 4.\(^1\) Next, we export the data from the forms into a .csv file. Then, we run a script to import the extracted data into our database.

Our script automatically checks for the consistency of data provided by the authors. If our script identifies that the two authors extracted different data for a given paper, the script generates a `diff` containing the different content beside each other. The `diff` files support the resolution of disagreements (Step 8 on Figure 1), in which both authors would check the `diff` files and reach consensus regarding which data should be extracted and imported.

\(^1\) Available at https://www.mendeley.com/

| Extraction Form Fields | Sub items |
|------------------------|-----------|
| F1                     | What are the claims presented in the paper? |
| F2                     | What are the variables related to each claim? (And, if it is not clear, what is the meaning of each variable?) |
| F3                     | What kind of study was performed to evaluate the claim? |
| F4                     | How the claim was evaluated? |
| F5                     | How many projects were involved in the study? |
| F6                     | Are there open-source, industry, or both classes of projects involved in the study? |
| F7                     | Is the study focused on a specific domain area? which one? |
| F8                     | Does the study have the artefacts available? |
| F9.1                   | Integration Frequency |
| F9.2                   | Automatic Build |
| F9.3                   | Build Duration |
| F9.4                   | Automated Tests |
| F9.5                   | Test Coverage |
| F9.6                   | Integration on Master |
| F9.7                   | CI SERVICE |

Table 4 Fields of the extraction form.
into the database (step 9 on Figure[1]). Examples of inconsistencies include typing errors or misunderstandings of how the data should be extracted.

3.5 Synthesis

We use the data extracted from our extraction form (Table 4) to address RQ1, RQ2, and RQ3 (Section 3.1). We first analyze the demographic data. Next, we perform the analyses to answer the others RQs. To answer RQ1—What are the existing criteria to identify whether a software project uses CI?, we use the F9 field. To answer RQ2—What are the reported claims regarding the effects of CI on software development?, we run a thematic synthesis [7] using the fields F1 and F2. To answer RQ3–Which empirical methods, projects and artifacts are used in the studies that investigate the effects of CI on software development?, we use fields from F3-to-F8 (see Table 4).

In the thematic synthesis to answer RQ2, we follow the steps recommended by Cruzes & Dyba [7]. The thematic synthesis consists of identifying patterns (themes) within the data, which provides a systematic manner to report the findings of a study. The thematic synthesis consists of five steps:

1. Extract data,
2. Code data,
3. Translate codes into themes,
4. Create a model of higher-order themes, and
5. Assess the trustworthiness of the synthesis.

The Extract Data is the first step of the thematic synthesis (Section 3.4). To answer RQ2, we analyze the data from fields F1 and F2 (see Table 4), which are claims regarding the effects of CI, i.e., any consideration in a study indicating a positive or negative effect of CI on the software development phenomena. Therefore, we do not consider to be a claim statements that are indirect or unrelated to the effects of CI on software development—even if CI is used by the software projects under investigation.

We group the information from fields F1 and F2 in a spreadsheet. Next, we code the information through an inductive approach [7], i.e., two authors analyze all the claims together and collaboratively assign one or two codes to each of the claims. The assigned codes are based on the central message within a claim. Therefore, the two authors create an established list of codes.

Once the list of codes is created, two other authors are debriefed regarding the codes to understand their meanings. These two other authors revisit every claim independently and select one or more coders from the list of codes to assign to the claims. As an example, consider the following finding in study P25: “After adoption of CI, normalized collaboration amount between programmers significantly increases for our set of OSS and proprietary projects. [...]”. Both authors assign the code “CI IS ASSOCIATED WITH AN INCREASE IN COOPERATION” to such a claim. At this stage, we obtain a Cohen Kappa statistic [5] of 0.73, which indicates a substantial agreement. All disagreements were solved by a third author.

As an example of a disagreement, consider the following claim in study P74: “Core developers in teams using CI are able to discover significantly more bugs than in teams not using CI. [...]”. One author assigned the code “CI IS ASSOCIATED WITH DEFECT REDUCTION”, while the other author assigned “CI IS ASSOCIATED WITH A DECREASE...”
Table 5  Extracted claims from studies P25 and P74, from fields F1 and F2 of the extraction form.

| Claim                                                                 | Variables                                                      | Paper id |
|----------------------------------------------------------------------|----------------------------------------------------------------|----------|
| CI increases normalized collaboration amount between programmers (OSS and proprietary projects) | Normalized median in-degree (NMID)                             | 25       |
| Core developers in teams using CI are able to discover significantly more bugs than in teams not using CI | Number of bug reports (i.e. issues clearly labeled as bugs)    | 74       |

In this case, the third author analyzed the claim and decided to maintain the code “CI IS ASSOCIATED WITH DEFECT REDUCTION”.

In the third step of the thematic synthesis (i.e., Translate codes into themes) we compute the frequency of each code and propose overarching themes. Finally, we develop a thematic network to express the relationship between codes and themes (Step 4 of the thematic synthesis). Once the thematic network was developed we performed two meetings with all authors to discuss the meaningfulness of the network and codes (Step 5 of the thematic synthesis). After 4 hours of discussion (each meeting having 2 hours), we refined the thematic network and the codes and themes within it.

3.6 Quality Assessment

In our extraction form (Table 4), fields F3 to F9 provide us the necessary information to evaluate the quality of our target studies (and the quality of their scientific claims). We discuss the quality of the studies in Section 4.4.2 and Section 5.2. For example, we analyze the kind of study that is supporting certain claims and the specific evaluation methods for those claims. Section 5.2 also discusses the strength of the findings or the lack of specific kinds of studies that would be necessary to strengthen the findings. Section 5.1 reflects on the environment in which the claims are formulated by discussing the criteria to select and describe the projects under analysis.

4 Results

In this section we present the results of our systematic literature review (SLR). The following subsections explores demographic information and results to our research questions.

4.1 Demographic attributes

This subsection shows the demographic data of our primary studies. We discuss the evolution of studies over the years and describe the authors’ information next.

Evolution of studies. CI emerged in the context of eXtreme Programming, a software development methodology that increased and became popular in the late 90s and early 00s [18]. Indeed, we identify the first research efforts on CI in 2003. Figure 2 shows an increasing number of publications over the years, especially in the last five years. The majority of papers have been published in conference proceedings (69 papers, i.e., 67.2%), followed by 23 papers published in journals (i.e. 22.5%). 10 other studies have been published in workshops in the last years (i.e. 9.8%).
Our primary studies have been published in 29 distinct conferences, 15 journals, and 7 workshops. Figure 3 (a) shows that MSR (IEEE International Working Conference on Mining Software Repositories), ICSE (International Conference on Software Engineering), Agile Conference, and ESEC/FSE (European Software Engineering Conference and ACM SIGSOFT Symposium on the Foundations of Software Engineering) are the conferences with highest number of primary studies.

As for workshops, Figure 3 (b) shows Conference XP (Scientific Workshops Proceedings), SWAN (International Workshop on Software Analytics), and RCoSE (International Workshop on Rapid Continuous Software Engineering) as the most frequent venues. Figure 3 (c) shows that the journals with the highest frequency are Empirical Software Engineering, Information and Software Technology, and IEEE Software.

**Paper Authors.** The primary studies have 259 different authors involved altogether. Table 6 shows a ranking with those having the highest number of publications included as a primary study in our SLR. Jan Bosh is the most frequent author and all of the top 6 researchers remain active over the last years. Having described the demographic data of our primary studies, we now describe our obtained results.
4.2 RQ1: What are the existing criteria to identify whether a software project uses CI?

To answer this research question, we analyze in the primary studies which criteria (e.g., CI practices or attributes) were considered when describing or selecting the analyzed projects—For example, how are the projects using CI deemed as such?. More specifically, we investigate whether our primary studies select their projects based on the following criteria: integration frequency, automated build, build duration, automated tests, test coverage threshold, integration on the mainline, and CI service. These criteria are inspired in the Duvall’s seven cornerstones [11] and CI practices highlighted by Fowler [17].

Fig. 3  Publications in main venues on (a) conferences, (b) Workshops, and (c) Journals.

Fig. 4  (a) Histogram representing the proportion of primary studies using a number of CI criteria; (b) Frequency of usage of each criteria;
Table 7 CI Services cited in the included studies.

| CI Services                          | Studies |
|-------------------------------------|---------|
| TRAVIS CI                           | 37      |
| JENKINS                             | 8       |
| CUSTOMIZED                          | 4       |
| CIRCLE CI                           | 3       |
| APPVEYOR, TEAM CI, WERKCI           | 2       |
| BUILDBOT, CONCOURSE, CRUISECONTROL,| 2       |
| GERRIT, CLOUDBEES, XCODE, BOTS, GITLAB | 1       |

Figure 4 (a) shows the number of criteria considered in the primary studies to identify whether a project uses CI. From the seven considered criteria that we expect to see, 43 (42.5%) of the primary studies, surprisingly, did not apply or determine any of them. On the other hand, 26 (25.7%) of the primary studies used two criteria, while 16 (15.8%) of the projects and another 16 (15.8%) of them used one and three criteria, respectively.

By inspecting the 43 (42.5%) studies without clear criteria for determining whether a project uses CI, we observe that: (i) 28 of the studies do not analyze data related directly to the development of the project. Instead, they are studies based on interviews, surveys, companies, or other kind of data, e.g., build logs; (ii) some of the studies present experience reports without further details regarding how projects adopt the CI practices. In addition, (iii) a few number of studies (P49, P52, P60, P69) analyze both projects and self-described declarations, like interviews or survey.

Although it is understandable that the criteria we are looking for (e.g., integration frequency) may not be applied in such studies, it would still be valuable to perform certain checks during the interviews or surveys. For example, questions such as “on a scale of 1 to 7, how would you classify that your project adhere to CI?” along with a definition of CI could help such studies to gauge the quality the CI practices that are implemented by the subjects. Regarding the studies that investigate build logs only (e.g., build logs from TRAVIS CI), it would also be desirable to be more restrictive regarding these logs, since not every build log from TRAVIS CI may come from a project that properly employs CI. Therefore, solely relying on the fact that build logs are generated from a CI server does not necessarily imply that the derived observations can be associated with the adoption of CI practices.

With respect to studies applying only one criterion to identify whether a project uses CI, the CI server configuration is the most common criterion (9/16 studies - 56.25%). We observe in Figure 4 (b) that the usage of a CI service is the most common criterion applied. This criterion consists of checking whether subject projects have used a CI service (e.g., TRAVIS CI). The second most frequent criterion is checking whether subject projects perform automatic builds. Table 7 shows the CI services cited in the included studies, revealing that TRAVIS CI is the most used CI service, confirming the finding by Hilton et al. [21].

4.3 RQ2: What are the reported claims regarding the effects of CI on software development?

To answer RQ2, we collect the claims from our primary studies and proceed with the thematic synthesis to produce the codes and themes regarding the claims. As explained in Section 3.5, a claim is a statement regarding any positive or negative effect of CI on the software development process.
development phenomena. We found 125 claims regarding the effects of CI in 38 out of 101 papers (37.6% of studies). From the thematic synthesis, we produce 31 codes from the 125 extracted claims. Figure 5 shows the produced codes organized into 6 overarching themes.

Table 8 shows the following information: a) the themes, b) the number of claims pertaining to a theme, and c) the primary studies that make the claims. The most common themes in the primary studies are: “development activities”—which was mentioned 35 times in 18 papers—and “software processes”—which was mentioned 35 times in 18 studies. Although we observe in RQ1 that automated builds is a common criterion to check whether CI is employed by subject projects, the theme “build patterns” has only 7 occurrences from 4 primary studies.

Fig. 5 Themes and codes representing the studies claims.
Table 8 Number of claims and studies that pertain to a theme.

| Theme                      | Number of Claims | Primary Studies                                                                 |
|----------------------------|------------------|---------------------------------------------------------------------------------|
| Development activities     | 35               | P7, P9, P31, P39, P52, P58, P59, P73, P79, P74, P90, P91, P93, P97, P99, P100, P102, P106 |
| Software process           | 35               | P4, P24, P25, P38, P40, P46, P52, P58, P64, P79, P81, P92, P93, P97, P100, P102, P105, P106 |
| Quality assurance          | 23               | P14, P29, P44, P52, P58, P64, P69, P79, P89, P93, P97, P100, P102, P106           |
| Integration patterns       | 22               | P25, P47, P59, P74, P79, P81, P89, P97, P100, P102, P104                         |
| Issues & defects           | 14               | P25, P31, P59, P74, P79, P97, P100, P102                                       |
| Build Patterns             | 7                | P29, P49, P97, P102                                                             |

4.3.1 Development Activities

Several primary studies have claims regarding the effects of CI on development activities. Table 9 shows the claims made in these primary studies, the development activity to which these claims are related, and the ID of the primary studies supporting the claims. We observe 4 positive effects of CI on productivity and efficiency, confidence, satisfaction, and reduction in the workload.

Table 9 Codes from the “development activities” theme. We show the number of occurrence of the code and the primary studies supporting the code.

| Code                                                   | Number of occurrences | Primary Studies                                                                 |
|--------------------------------------------------------|------------------------|---------------------------------------------------------------------------------|
| CI is related to productivity and efficiency increase | 12                     | P31, P39, P52, P59, P73, P79, P74, P97, P100, P102, P106                       |
| CI is associated with Confidence improvement           | 6                      | P39, P58, P93, P97, P100, P106                                                |
| CI may generate a false sense of confidence            | 5                      | P7, P58, P106                                                                  |
| CI is associated with a workload reduction             | 3                      | P6, P79, P93                                                                  |
| CI is associated with human challenges                 | 2                      | P58, P59                                                                      |
| CI is associated with a decreased perception of productivity | 1                     | P91                                                                           |
| CI is associated with an improvement in satisfaction    | 1                      | P9                                                                            |
| CI is associated with organizational challenges         | 1                      | P99                                                                           |
| CI is associated with a decrease in magnetism and retention | 1                  | P90                                                                           |

There are several mentions in the primary studies claiming an increase in productivity and efficiency when using CI (12 occurrences in 11 studies). As reported in study P97:
“According to our interview participants, CI allows developers to focus more on being productive, and to let the CI take care of boring, repetitive steps, which can be handled by automation.” (p. 203)

And

“Another reason [...] was that CI allows for faster iterations, which helps developers be more productive.” (p. 204)

Several studies also mention an improvement in confidence after using CI (6 occurrences in 6 papers). Paper P58 states the following:

“Depends on the coverage, but some sort of confidence that introduced changes don’t break the current behavior. [...] I assume the most critical parts of the system have been covered by test cases.” (p. 76)

Nevertheless, not everything seems to be positive in terms of development activities. We found six negative aspects stated in the primary studies: extra complexity added, the existence of a false sense of confidence, human challenges, a decreased perception of productivity, organizational challenges, and a decrease in magnetism and retention of collaborators in projects. The most endorsed negative effects of CI are the addition of extra complexity (5 occurrences in 3 papers), and the generation of a false sense of confidence (3 occurrences in 2 studies). P7 mentions the extra complexity related to using CI:

“Results of our study [...] highlights the complexity of dealing with CI in certain situations, e.g., when dealing with emulated environments, non-deterministic (flaky) tests, or different environments exhibiting an inconsistent behavior”. (p. 47)

P106 explains the false sense of confidence:

“As opposed to the confidence benefit, respondents described the false sense of confidence as a situation of which developers blindly trust in tests” (p. 2232)

CI has positive effects on developers’ productivity and workload, improving her/his confidence and satisfaction. On the other hand, CI is also reported to add extra complexity to software development.

4.3.2 Software Process

In this theme, we group codes related to the effects of CI on the software processes. Table 10 presents the codes, the number of occurrences, and the primary studies in which the codes appear. CI adoption is believed to be a factor of success in software projects according to study P92, bringing benefits to software development, such as more cooperation within and between teams (P25):

“After adoption of CI, normalized collaboration amount between programmers significantly increases for our set of OSS and proprietary projects.”. (p. 12)

Automation improvement and process reliability are other benefits, as stated by a participant of study P97:

“CI allows developers to focus more on being productive, and to let the CI take care of boring, repetitive steps, which can be handled by automation.”. (p. 203)
In addition to these benefits, the studies also report a better predictability of release cycles, and faster feedback. As an example, P46 states:

“The integration tool-chain enabled shorter feedback cycles for the software developed in-house—from feedback loops stretching several weeks, the department could now integrate the latest changes in a matter of hours.”. (p. 4)

Table 10 Codes from theme “Software Processes”. We show the number of occurrences and the primary studies.

| Code                                      | Frequency | Papers |
|-------------------------------------------|-----------|--------|
| CI is related to positive impact on release cycle | 7         | P58, P64, P97, P100, P102 |
| CI is associated with an increase in cooperation | 8         | P25, P52, P79, P81, P93, P106 |
| CI is associated with an improvement in process reliability | 7         | P46, P52, P79, P92, P105, P106 |
| CI is associated with technical challenges | 6         | P4, P24, P38, P58, P97 |
| CI is associated with an improvement in process automation | 3         | P58, P97, P106 |
| CI is associated with software development benefits | 3         | P40, P92, P105 |
| CI is associated with a feedback frequency increase | 1         | P46 |
| CI facilitates the transition to agile     | 1         | P46 |

A potential negative effect of CI in the Software Process are the technical challenges associated with adopting CI (6 occurrences in 5 studies), confirming the addition of extra complexity (see Section 4.3.1). For example, study P58 states:

“As regarding the hidden problems associated with continuous integration usage, we found that 31 respondents are having a hard time configuring the build environment”. (p. 76)

The studies highlight the difficulty in implementing CI as well as setting up the environment, especially to newcomers (by confirming problems of magnetism and retention of developers (see Section 4.3.3)). Moreover, some studies state that the lack of maturity of technology may contribute to the abandonment of CI, as stated in study P24:

“Results show that all of the 13 interviewees mentioned challenges related to tools and infrastructure such as code review, regression feedback time when adopting to CI. The maturity of the tools and infrastructure was found to be a major issue.”(p. 29)

CI is mentioned as a factor of success in software projects, having a positive effect on software processes. However, CI may also bring technical challenges, such as properly setting up the CI environment.

4.3.3 Quality Assurance

Another significant theme brought by our primary studies is the “Quality Assurance” theme. As shown in Table [11] CI is associated with a continuous practice of quality assessment
(P44), refactoring (P44), finding problems earlier (P58), and improving the code quality (P58, P64, P97, P106).

According to the primary studies, the adoption of CI tends to increase the volume and coverage of tests. CI also encourages best practices of automated test ranging from tests within private builds to functional tests on the cloud. The support to multi-environment tests is also mentioned as a support to a “real-world environment”. For example, study P89 states:

“After some (expected) initial adjustments, the amount (and potentially the quality) of automated tests seems to increase.” (p. 69)

In the same way, study P97 remarks:

“Developers believe that using CI leads to higher code quality. By writing a good automated test suite, and running it after every change, developers can quickly identify when they make a change that does not behave as anticipated, or breaks some other part of the code.” (p. 203)

CI stimulates the test discipline, supporting test diversity, and good practices. Literature reports quality assurance as a constant concern to improve code quality.

Table 11 Codes from the “Quality Assurance” theme. We show the number of occurrences and the respective primary studies.

| Code                                           | Number of occurrences | Studies                      |
|------------------------------------------------|-----------------------|------------------------------|
| CI is related to positive impact on test practice | 10                    | P14, P29, P52, P89, P93, P97, P100, P102, P106 |
| CI is related to an increase on quality assessment | 8                     | P44, P58, P64, P69, P79, P97 |
| CI is associated with to favor continuous refactoring | 1                     | P44                          |
| CI is associated to multi-environment tests      | 4                     | P58, P97, P100, P106         |

4.3.4 Integration Patterns

The “Integration Patterns” theme consists of claims related to commits and pull requests, as shown in Table 12. Some primary studies report that CI adoption increases the number of pull requests submissions (P81). CI also helps in identifying and rejecting problematic code submissions faster (P69, P100). However, the time to integrate the pull requests might become slower after adopting CI (P100, P81). P81 states that:

“Open source projects that plan adopt CI should be aware that the adoption of CI will not necessarily deliver merged PRs more quickly. On the other hand, as the pull-based development can attract the interest of external contributors, and hence, increase the projects workload, CI may help in other aspects, e.g., delivering more functionalities to end users.” (p. 140)

The study P81 also indicates that CI can be associated with an increase in the pull request life-cycle:
“We observe that in 54% (47/87) of our projects, PRs have a larger lifetime after adopting CI.” (p. 134)

Moreover, studies also mention that CI can ease the practice of code integration (5 occurrences in 5 papers). These studies mention that CI can make integration easier (P97, P100), reduce integration stress (P59), and even support a faster integration (P79, P102). Such facilities are also a motivation for adopting CI. As P100 states:

“One reason developers gave for using CI is that it makes integration easier. One respondent added ‘To be more confident when merging PRs.’” (p. 433)

CI facilitates the developer integration process. However, there are some mentions of the negative impact of CI regarding the pull request life cycle.

Table 12 Codes from the “Integration Patterns” theme. We show the number of occurrences and the respective primary studies.

| Code                                             | Number of occurrences | Studies          |
|--------------------------------------------------|-----------------------|------------------|
| CI is related to positive impact on pull request life-cycle | 9                     | P47, P69, P74, P81, P89, P100 |
| CI is associated with a commit pattern change     | 5                     | P25, P89, P102   |
| CI is associated with a positive impact on integration practice | 5                     | P59, P79, P97, P100, P102 |
| CI is related to negative impact on pull request life-cycle | 3                     | P81, P104        |

4.3.5 Issues & defects

The manner by which projects adopting CI handle defects, bugs, and issues is grouped under the “Issues & Defects” theme. Table 13 shows three codes under this theme. There are 8 mentions in 7 different studies that show the relationship between CI and the increase in addressed issues or bugs defects. These studies also mention a decrease in defects or bugs reported. For instance, in study P50 it is stated that:

“The descriptive statistics point to an overall improvement in not only finding more defects (defect reduction), but also in shortening the time required to fix the defects (defect lead and throughput).” (p. 8)

We observe other 6 mentions in 6 papers stating that CI helps development teams to find and fix bugs and broken builds, as stated in P59:

“An indirect, but important, advantage of CI is related to the following human factor: the earlier the developer is notified of an issue with the patch that was just committed, the easier it is for him or her to associate this regression with specific changes in code that could have caused the problem and fix it.” (p. 9)

CI contributes to a reduction in time to find and fix defects and increase the issues resolution rate.
Table 13  Codes from the “Issues & Defects” themes. We show the number of occurrences and the respective primary studies.

| Code                                           | Number of occurrences | Studies                      |
|------------------------------------------------|-----------------------|------------------------------|
| CI is associated with defect reduction         | 6                     | P25, P31, P50, P74, P79      |
| CI is associated with issues reduction         | 2                     | P25, P89                     |
| CI is associated with a decrease in time to lead defects | 6                     | P50, P59, P79, P97, P100,    |
|                                                |                       | P106                         |

4.3.6 Build Patterns

The “Build Patterns” theme encompasses the reported associations between CI and build metrics. Table 14 shows two codes representing the “Build Patterns” theme. Under the code “CI is associated with build health”, 6 mentions in 4 studies report developers’ good practices encouraged by CI, as well as an improvement in build success rate (P49, P102). CI encourages good practices that contribute to build health, such as test in private builds (P29), prioritization to fix broken builds (P29), and support a shared build environment (P97). P97 states the following:

“Several developers told us that in their team if the code does not build on the CI server, then the build is considered broken, regardless of how it behaves on an individual developer’s machine. For example, S5 said: ‘...If it doesn’t work here (on the CI), it doesn’t matter if it works on your machine.’” (p. 202)

P102 also reports a decrease in the build duration:

“The following observations were made after successfully deploying our CI and Testing framework in place: [...] Short Build and Integration times [...]” (p. 747).

CI promotes good practices related to build health, contributes to an increase in successful builds, and decreases build time.

Table 14  Codes from the “Build Patterns” theme. We show the number of occurrences and the respective studies.

| Code                                           | Number of occurrences | Studies                      |
|------------------------------------------------|-----------------------|------------------------------|
| CI is associated with build health             | 6                     | P29, P49, P97, P102          |
| CI is associated with a decreasing in build time | 1                     | P102                         |

4.4 RQ3: Which empirical methods, projects and artifacts are used in the studies that investigate the effects of CI on software development?

In this RQ we investigate the methodologies applied in the primary studies. In particular, we analyze: the kind of projects that our primary studies analyze (Section 4.4.1), the study methodologies, i.e., the kind of the studies and the evaluation methods applied (Section 4.4.2), and the availability of the artifacts produced as part of these studies (Section 4.4.3).
Table 15  Applications domains investigated in primary studies.

| Domain                        | Occurrences |
|-------------------------------|-------------|
| Transports                   | 4           |
| Embedded systems             | 4           |
| Telecommunications           | 3           |
| Software Development         | 3           |
| Web Application              | 2           |
| Finance                      | 2           |
| Cloud Computing              | 2           |
| Military Systems             | 2           |
| Home and office solutions    | 1           |
| Bookmaking company           | 1           |
| Mobile software and social networks | 1    |
| Health care                  | 1           |
| HPC environment              | 1           |
| Serverless applications      | 1           |
| Neuroinformatics             | 1           |
| Databases migration          | 1           |

4.4.1 Projects analyzed

Figure 6(a) shows information about the type of projects that were investigated in CI studies. We can observe that 40 of 101 studies (39.6%), analyze only open source projects. In contrast, 18 studies (17.8%) investigate private projects. On the other hand, 40 of the studies (39.6%) are not explicit about licenses of the projects, and 3 (3%) studies analyze mixed project settings, i.e., both open source and private projects.

![Proportion of studies based on the type of projects they analyze](image)

Figure 6(b) shows that 71 out of 101 studies (70.3%) do not investigate projects from a specific domain. On the other hand, 30 studies (29.7%) investigate domain specific projects. For studies investigating specific project domains, we catalog 17 different domains (see Table 15). The most frequent domains are: transports (4 occurrences), embedded systems (4 occurrences), telecommunications (3 occurrences), and software development (3 occurrences).
60 out of 101 studies focus on analyzing the historical data of software projects (e.g., production code or tests). The other remaining studies conducted interviews, surveys, or analyzed other units of information different from projects’ source code, e.g., builds or companies. Figure [7] shows the descriptive statistics of the projects that were analyzed per study. We hide outliers for readability purposes—the highest outlier has 34,544 projects. While the mean of analyzed projects is 1,493 projects, the median is just 40, with a high frequency of studies analyzing just 1 or 2 projects. Some studies seem to be outliers, such as P72, which investigated 13,590 projects, and P100, which investigated 34,544 projects.

The P100 study uses a large corpus of projects (i.e., 34,544 projects) for specific investigations. For example, the large corpus of projects is used to identify which CI services are mostly used. However, to perform more specific investigations, P100 uses only a subset of the total corpus of projects (i.e., 1,000 projects). P72 highlights the TRAVIS TORRENT [3] dataset, which is a widely known dataset of projects from GITHUB that collates build logs from TRAVIS CI.

Fig. 7 Boxplot and descriptive statistics of the projects that were analyzed by our primary studies.

4.4.2 Study Methodologies

Figure [8] (a) shows the proportion of claims per type of study. The categories are (i) Mining Software Repository (MSR) studies and the other four classical empirical methods for software engineering [13]: (ii) controlled experiment, case study, survey, and action research. Figure [8] reveals that survey research was the method applied the most with respect to the extracted claims (47.2% - 59 claims)—followed by case studies (19.2% - 24 claims) and MSR (17.6% - 22 claims). Only 7 (5.6%) of the claims are associated with a mixed-methods approach combining survey and MSR methods, which comes from 3 studies (P4, P7, and P89).

During the extraction phase (Section 3.4), we record how the study evaluated the findings and formulate a claim. Table [16] reports the identified methods. We extract methods ranging from statistical tests, such as Cliff’s delta, and Mann-Whitney test, to qualitative methods such as thematic analysis, and triangulation between interviews and surveys. Some
of the studies, however, do not make it clear in their methodology which methods or evaluation criteria are used. Therefore, we consider claims that went under evaluations to be more reliable than those without such explicit evaluations.

From a total of 125 claims, we could identify the evaluation methodology of 49.6% claims (62 claims). As shown in Figure 8(b), all claims extracted from controlled experiments, mixed survey and MSR studies have evaluation methods that are clearly stated. When considering case studies and surveys we can only identify the evaluation methodology for 41.6% and 33.9% of the claims, respectively. Unfortunately, claims extracted from action research and other types of studies have no clear definition about their evaluation methodology.
4.4.3 Availability of Artifacts

Robles [31] investigated the MSR conference papers from 2004 to 2009. He found that the majority of published papers are hard to replicate. For example, although 64 out of 171 papers (37.4%) are based on publicly available datasets, these datasets are in the “raw” form and the papers do not provide the processed version of the datasets nor the tools that were used to process these datasets. Another 18.12% of papers (i.e., 31 papers) do not even provide the “raw” data to begin with.

Rodríguez-Pérez et al. [28] capitalize on the same issue of data availability and raise the concern about the reliability of the results from studies that are not reproducible studies. On the other hand, they [28] also report the increasing attention that the community has given to the issue of data availability over the last years. Therefore, in our study, we collect information about the availability of the artifacts used or produced in the primary studies, considering those that analyze projects. Figure 9 (a) reveals that 29 studies out of 60 (48.33%) provide publicly available datasets, while 31 studies (51.66%) do not provide publicly available datasets. From the studies providing publicly available datasets, all of them are studies using open source projects. On the other hand, those studies investigating private projects do not present dataset nor anonymized nor in a raw manner, while some of the studies with mixed—both private and open source—projects provide only partial data referring to OSS projects. Other studies are not explicit regarding whether the dataset comes from private or OSS projects and does not present it.

Figure 9 (b) shows an increasing trend of pushing for data transparency in CI studies. Over recent years, we observe that the proportion of studies providing a publicly available dataset is higher than 50% (we consider only studies that analyze projects data). This increase in transparency might be due to initiatives from prominent conferences, such as the artifact tracks, in which authors are provided with special badges as a credit for their effort invested in sharing their artifacts. Nowadays, there are even awards to encourage the sharing of reproducible artifacts.

Fig. 9 (a) Proportion of studies according to data availability; (b) Proportion of transparency over the years.

[3] https://icsme2020.github.io/cfp/ArtifactROSETackCFP.html
5 Discussion

In this section, we provide a discussion of the results that we presented in the previous section. First, we identify and discuss potential limitations of the existing literature. Next, we discuss our findings regarding the methodologies of our primary studies. Afterwards, we highlight research opportunities based on our observations.

5.1 CI Environment and Study Results

In our study, we find that 42.5% (43) of the CI studies are not associated with any specific criteria (see Section 4.2) to identify whether the implementation of CI is up to standards. On the other hand, 15.8% (16) of studies apply one criterion. The results in an alarming proportion of 58.3% of primary studies having none or only one criterion to identify whether CI has been implemented in a project. This is alarming because this suggests that most of the existing claims regarding CI might be biased towards projects that do not fully implement CI. The most frequent criterion specified for 45.5% of the studies is the usage of an online CI service (see Figure 4 (b)), which allows implementing a CI pipeline for existing projects. This finding represents a challenge to be overcome by the research community, since other studies revealed that CI usage may be inconsistent, sporadical, or discontinued [40].

Vasilescu et al. [40] investigated quality and productivity outcomes with respect to CI. From a dataset of 918 GitHub projects that used TRAVISCI, they found that only 246 projects have a good level of activity using TRAVISCI, while the other 672 projects have used TRAVISCI only for a few months. It suggests that solely relying on CI service configuration is not enough to determine a proper CI adoption.

Vassalo et al. [39] performed survey with 124 professional developers confirming that deviations from CI best practices occur in practice, and can be the cause of CI degradation. They mined 36 projects and verified relevant instances of four anti-patterns [12]: late merging, slow build, broken release branch, and skip failed test.

Felidre et al. [16] also investigated CI bad practices, beyond slow build and broken release branch, they shed light on infrequent commits and poor test coverage. Their analysis of 1,270 open source projects confirmed the existence of a phenomenon known by practitioners as CI Theater, which refers to self-proclaimed CI projects that do not really implement CI [4].

Considering the findings observed in Section 4.2 and the above mentioned studies, we suspect that there is a lack of studies considering a more robust number of criteria in order to perform a more rigorous evaluation of CI adoption. This is especially true if we consider CI as a set of practices, where its benefits and challenges are directly related to the employment of the set of practices.

5.2 Study Methodologies and CI Claims

In our thematic synthesis in RQ2 (Section 4.3), we observed codes grouping claims with and without explicit support from evaluation methods. For example, on the theme “Development Activities”, the code “CI is related to productivity and efficiency increasing” is supported by 11 studies, of which only 5 studies (P52, P59, P74, P79, P97) provide support from evaluations (see Table 16). However, there are 6 studies (P31, P39, P73, P100, P102, P106) that do not provide support from evaluations. Another example is the code “CI is associated
with defect reduction” under the theme “Issues & Defects”. Five studies state this claim (i.e., P31, P50, P25, P74, P79). In particular, three studies (P25, P74, P79) have clear evaluation support (Cliff’s delta / Mann-Whitney test, regression model, and descriptive statistics). On the other hand two studies (P31 and P50) do not present any evaluation for their claim.

| Theme                        | Code                                           | Quantitative | Qualitative | Evaluated Claims |
|------------------------------|------------------------------------------------|--------------|-------------|------------------|
| BUILD PATTERNS               | CI is associated with build health             |              |             | 50%              |
|                              | CI is associated with a decreasing in build time |              |             | 0.0%             |
| QUALITY ASSURANCE            | CI is related to positive impacts on test practice |              |             | 60.0%            |
|                              | CI is related to an increase quality assessment |              |             | 25.0%            |
|                              | CI is associated with to favor continuous refactoring |              |             | 0.0%             |
|                              | CI is associated to multi-environment tests     |              |             | 25.0%            |
| INTEGRATION PATTERNS         | CI is related to positive impacts on pull requests life-cycle |              |             | 88.9%            |
|                              | CI is related to negative impacts on pull requests life-cycle |              |             | 100.0%           |
|                              | CI is associated with a positive impact on integration practice |              |             | 40.0%            |
|                              | CI is associated with a commit pattern change   |              |             | 80.0%            |
| ISSUES & DEFECTS             | CI is associated with defects reduction         |              |             | 66.8%            |
|                              | CI is associated with issues reduction          |              |             | 100.0%           |
| DEVELOPMENT ACTIVITIES       | CI may generate a false sense of confidence    |              |             | 0.0%             |
|                              | CI is associated with confidence improvement   |              |             | 33.3%            |
|                              | CI is related to productivity and efficiency increasing |              |             | 50.0%            |
|                              | CI is associated with adding extra complexity   |              |             | 20.0%            |
|                              | CI is associated with a workload reduction      |              |             | 66.7%            |
|                              | CI is associated with a decreased perception of productivity |              |             | 100.0%           |
|                              | CI is associated with an improvement in satisfaction |              |             | 100.0%           |
|                              | CI is associated with organizational challenges |              |             | 100.0%           |
|                              | CI is associated with human challenges          |              |             | 0.0%             |
|                              | CI is associated with a decrease in magnetism and retention |              |             | 100.0%           |
| SOFTWARE PROCESS             | CI is related to positive impacts on release cycle |              |             | 28.6%            |
|                              | CI is associated with an increase in cooperation |              |             | 87.5%            |
|                              | CI is associated with an improvement in process reliability |              |             | 71.4%            |
|                              | CI is associated with an improvement in process automation |              |             | 33.3%            |
|                              | CI facilitates agile transition                 |              |             | 0.0%             |
|                              | CI is associated with technical challenges      |              |             | 50.0%            |
|                              | CI is associated with software development benefits |              |             | 66.7%            |
|                              | CI is associated with a feedback frequency increase |              |             | 0.0%             |

Table 17 presents the types of evaluation performed to support each code. Quantitative evaluation methods support some of them, others by qualitative ones, and a minor amount by both kinds. We observed six codes for which evaluation has not been performed. The code “CI is associated with a decreasing in build time” from the “Build Patterns” theme, for example, is supported by only one study (P102), which does not provide evaluations to support the claim. Table 18 highlights such cases with their associated codes and themes. These identified claims that are not systematically evaluated in existing studies represent an opportunity for researchers to deepen and strengthen the knowledge on these topics.
Table 18 Codes having claims without evaluation.

| Code                                                | Theme             |
|------------------------------------------------------|-------------------|
| CI is associated with a decreasing in build time     | Build Patterns    |
| CI is associated with to favor continuous refactoring| Quality Assurance |
| CI may generate a false sense of confidence          |                   |
| CI is associated with human challenges               | Development Activities |
| CI facilitates agile transition                      | Software Processes |
| CI is associated with a feedback frequency increase   |                   |

5.3 Research Opportunities

Beyond the weakness mentioned in the Section 5.2, this subsection discusses existing gaps in the research on continuous integration and apparent contradictions among the findings, especially focusing on the themes “integration patterns” and “development activities”.

5.3.1 Integration Patterns

Regarding the integration patterns theme, we can observe two sets of contradicting claims. The claims in Table 19 represents the following codes: (i) “CI is related to positive impact on pull request life-cycle” having six studies providing support (P47, P69, P74, P81, P89, P100); and (ii) “CI is related to negative impact on pull requests life-cycle” with two studies providing support (P81, P104). The observed contradiction consists mainly on the time to integrate a pull request.

While studies P81 and P104 claim that CI contributes to pull request latency, P100 and P69 claim positive contributions from CI. Based on an MSR study including 1,529,291 builds and 653,404 pull requests, P100 advocates that CI build status can make integrating pull requests faster. In line with this observation, in a series of interviews and survey, P69 reports that 87.23% of the respondents agree that CI can help to detect merging issues earlier and easier. On the other hand, P104 investigates 103,284 pull requests from 40 different projects and confirm the hypothesis that CI is a dominant factor of pull request latency. Finally, P81 analyzes 63 projects and concludes that pull requests are merged faster before CI adoption.

This apparent contradiction might be related to several factors, including (as observed earlier) the manner by which these studies determine whether projects are using CI or not. The main message here is that more studies are necessary to investigate the claims related to CI and pull-request life time.
Table 19 Claims related to the effects of CI on pull requests.

| CODE: CI positive impacts on Pull-Requests | Studies |
|-------------------------------------------|---------|
| CI build status contributes to faster pull request integration. | P100    |
| CI can help detect merging issues early and easily. | P69     |
| CI can promote faster pull request delivery. | P81     |
| CI projects tend to have more pull requests submission. | P81     |
| CI projects deliver more pull requests per release. | P81     |
| CI is a dominant factor of pull-request acceptance. | P47     |
| CI is associated with external contributors having fewer pull requests rejected. | P74     |
| CI helps to reject problematic pull requests. | P100    |
| CI projects have more closed pull requests. | P89     |

| CODE: CI negative impacts on Pull-Requests | Studies |
|-------------------------------------------|---------|
| CI is a dominant factor of pull request latency. | P81, P104 |

5.3.2 Development Activities

From the “Development Activities” theme, we find opportunities to construct a deep understanding of some reported phenomena, such as what we might call “confidence paradox” and the “productivity paradox”. The “confidence paradox” is marked by studies that make claims related to code “CI may generate a false sense of confidence”, while some studies raise claims under the code “CI is associated with confidence improvement”. The “productivity paradox” refers to the existence of studies claiming that “CI is related to an increase in productivity or efficiency”, while some studies claim that “CI is associated with a decreased perception of productivity”.

Confidence paradox. Table 20 shows the claims related to developer confidence. Six studies provide support to conclude that CI improves developer confidence (P39, P97, P100, P106, P58, P93). On the other hand, two studies claim that CI can promote a false sense of confidence (P58, P106).

Table 20 Claims related to the effects of CI developer confidence.

| CODE: CI is associated with confidence improvement | Studies |
|------------------------------------------------|---------|
| CI increases the confidence about the quality. | P39     |
| CI makes the team less worried about breaking build. | P97, P100 |
| CI improves the developers confidence to perform the required code changes. | P106, P58, P93 |

| CODE: CI may generate a false sense of confidence | Studies |
|------------------------------------------------|---------|
| The false sense of confidence is a recurring problem in CI. | P58, P106 |
| Flaky tests may challenge CI projects. | P106    |

P93 theorizes that CI allows programmers to assume himself/herself as single-programmer in a project, supporting an improvement in confidence. For instance, by relying on the lower number of new inconsistencies expected in each integration cycle, the developer can behave as if she was the only person modifying the code, reducing the cognitive tractability of programming. In the same line, P58 and P106 surveyed 158 CI users and report the perception of respondents that CI provides more confidence to perform the required code changes.
Other studies may help to better understand this boost in confidence. Developers seem to delegate quality assurance to CI service and rely on its feedback. P39, an experience report, sheds light to the improvement in confidence on product quality after CI adoption due to test automatization. P100 reports a survey with 407 respondents and reveals that the most common reason to use CI is the expectation that it makes developers less worried about breaking builds. After a triangulation between an interview and two surveys, P97 reports the same finding.

On the other hand, P58 and P106 also shed light on a reported problem of a false sense of confidence. This situation occurs when developers rely on an environment that may suffer from low quality or insufficient tests. This environment may provide a baseless trust and suggest an opportunity to practitioners and researchers to investigate and to supply developers with objective criteria and guidance in order to define a reliable CI context to avoid the mentioned false sense of confidence. For example, what minimum set of practices and metrics should we achieve before having a reliable CI environment and feedback that can be trusted?

**Productivity paradox.** Table 21 shows the claims related to development productivity. There are 12 claims in 11 studies supporting the code “CI is related to an increase in productivity and efficiency”, and one study claiming that “CI is associated with a decreased perception of productivity”.

P52 performs a case study with four projects and validates the hypothesis that CI contributes to an increase in the developer productivity due to parallel development and reducing tasks before checking in (i.e., committing). Through another case study, P59 confirms this claim, while P39 and P31 share different experience reports that record an increase in development efficiency and throughput per developer, respectively.

P73 reports interviews, and P97 presents a triangulation between an interview and two surveys. They both confirm the perceptions that CI increases productivity. By mining software repositories from 246 projects, P74 finds that external contributors tend to have fewer pull requests rejected if CI is adopted. Other studies such as P100, P102, and P106 also bring results corroborating this code.

In opposition to these studies and findings, P91 investigates the links between agile practices, interpersonal conflict, and perceived productivity. The P91 study presents a survey with 68 software developers and finds that CI is negatively connected to productivity:

“I have also showed that with higher scores on Continuous Integration and Testing came lower scores on this perceived productivity measurement. That means that the more continuous integration and testing the team conducts, the worse is the perceived team productivity. However, I do not have any external measurement of the productivity of the teams and can not draw conclusions on the actual productivity [...].” (p. 4)

These research works and respective findings (Table 19, Table 20, and Table 21), with its apparent contradictions, may represent a research opportunity to construct a better understanding about such phenomenon.
Table 21 Claims related to the effects of CI on development productivity.

| Claim                                                                 | Studies        |
|-----------------------------------------------------------------------|----------------|
| CI increases development efficiency (due to the automation of tasks and fast feedback) | P39, P52, P73, P59, P31, P97 |
| CI is associated with external contributors having fewer pull requests rejected. | P74 |
| CI decreases the debug time.                                           | P100, P79      |
| CI allows quickly grow of source code.                                 | P102           |
| CI speed up development practice.                                      | P106           |
| CI Reduced integration problems allowing the team to deliver software more rapidly | P79 |

| Claim                                                                 | Studies |
|-----------------------------------------------------------------------|---------|
| The CI adoption leads to a worsening in the perceived team productivity. | P91     |

6 Threats to validity

The goal of our SLR is to provide a summary of the effects of CI on the software development phenomena. We follow the guidelines provided by Kitchenham & Charters [23] to develop our review protocol while defining strategies to mitigate possible bias. However, as it happens to every study, our SLR is not without flaws and, in this section, we discuss the limitations of our study.

6.1 Search Strategy

The search strategy may have bias or limitations on its search string and expression power, the limitations on search engines, and publication bias, i.e., positive results are more likely to be published than negative [23]. To mitigate the search string threats, we apply several identified synonyms to reach the effects of continuous integration, the intervention studied. In addition, aiming to reduce the limitations of search engines, we use six different search engines including five formal databases and one index engine, following the recommendations from Chen et al. [6], thereby including journals and conferences publications—which contributes to publication bias mitigation.

6.2 Screening Papers

The screening and selection phase (see Section 3.3.2) follows the inclusion and exclusion criteria defined during the protocol definition, as recommended by Kitchenham & Charters [23] to mitigate the selection bias. In addition, the decision relied on the evaluation of two researchers and the agreement was measured using the Cohen Kappa statistic [5]. A substantial agreement was achieved both in the first screening (0.72) and in the snowballing phase (0.76). The disagreements were read and arbitrated by a third researcher.
6.3 Data Extraction

To reduce the possibility of bias in the data extraction phase, we proceed the following steps (see section 3.4) to mitigate it. First, the meta-data was retrieved in an automated process using the data obtained in Mendeley - the reference management tool adopted. To avoid mistakes or missing information, the processed meta-data was manually inspected by one researcher. Second, the definition of extraction form (see Table 2) was available in the review protocol and in a web host to all three readers. Third, to decrease the chances of inattention, lack of understanding, or any other reason for mistaken data collection, the reading of each paper was performed by two researchers that filled the extraction form independently. Fourth, to treat the disagreements in the extraction and also avoid bias, each pair discussed the extracted data to achieve a consensus.

6.4 Data Synthesis

As described in Section 3.5, our study explores quantitative (RQ1 and RQ3) and qualitative synthesis (RQ2). In the quantitative synthesis of RQ1 and RQ3, we present a summarization to create a landscape of the studies and point out some directions to researchers. In the qualitative analysis of RQ2, we follow the guidelines of Cruzes & Dyba [7] to perform a thematic synthesis. In the coding phase, to mitigate the threats of confirmation bias, we first use an inductive approach performed by two researchers to define the set of codes. Second, also to avoid a wrong grouping, two researchers coded all the extracted segments in an independent way (this step also achieved a substantial Kappa agreement rate - 0.73), and a third researcher resolve the disagreements. Finally, all the authors discuss and agree with the translation of the codes into the presented themes.

In Sections 4.3 and 5.3 we assess the trustworthiness of the synthesis in terms of type of studies, number of occurrences, and the relationship between the findings of different primary studies.

7 Conclusion

We perform a systematic literature review (SLR) on the effects of continuous integration on the software development phenomena. Our main goal is to summarise the existing empirical evidence and body of knowledge regarding CI to support a better decision process, avoiding overestimating or underestimating the results and costs of CI adoption. We collect and analyze empirical evidence from 101 primary studies ranging from 2003 to 2019, conducting quantitative and qualitative analyses.

Given our observed results, we believe that continuous integration still needs robust empirical research to evaluate whether its claimed benefits hold in practice. It is fundamental to apply efforts in the robustness of the methods and criteria to identify projects that use CI, also mitigating confounding factors, such as the pros and cons of isolated practices that make up CI, or practices that do not represent CI.

There is still a lack of empirical evidence for many claims in CI literature to understand the actual benefits and challenges of CI employment. Several reported claims have not been evaluated and supported by a systematic research method, e.g. the relationship between CI adoption and build duration, CI employment and feedback frequency, CI and continuous
refactoring, among others (see Table 18). Despite all the limitations of existing literature, the effects of CI on software development seem to be positive.

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A Selected Studies

| ID | Title                                                                 | Author(s)                                                                 | Year | Venue                                      |
|----|----------------------------------------------------------------------|--------------------------------------------------------------------------|------|--------------------------------------------|
| P2 | (No) influence of continuous integration on the commit activity in GitHub projects | Stephan Diehl, Daniel Anastassiou, Jascha Knack, Sebastian Baltes, Ralf Tymann | 2018 | SWAN - International Workshop on Software Analytics |
| P3 | A brief study on build failures in continuous integration: Cau- sation and effect | Bharavi Mishra, Saket Kumar Singh, Romit Jain | 2018 | ICACIE - Progress in Advanced Computing and Intelligent Engineering |
| P4 | A conceptual replication of continuous integration pain points in the context of Travis CI | Bogdan Vasulescu, David Gray Widder, Michael Hilton, Christian Kästner | 2019 | ESEC/FSE Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering |
| P5 | A Current Study on the Limitations of Agile Methods in Industry Using Secure Google Forms | Ashish Agrawal, L. S. Maurya, Mohd Aurangzeb Atiq | 2016 | International Conference on Information Security and Privacy |
| P6 | A Hundred Days of Continuous Integration                              | Ade Miller                                                              | 2008 | Agile Conference                             |
| P7 | A Study on the Interplay between Pull Request Review and Continuous Integration Builds | Massimiliano Di Penta, Confora Gerardo, Gabriele Bavota, Fiorella Zampetti | 2019 | SANER                                        |
| P8 | A Tale of CI Build Failures: An Open Source and a Financial Organization Perspective | Carmine Vassallo, Gerald Schermann, Fiorella Zampetti, Daniele Romano, Philipp Leitner, Andy Zaidman, Massimiliano Di Penta, Sebastian Panichella | 2017 | ICSME - International Conference on Software Maintenance and Evolution |
| P9 | Agile systems development and stakeholder satisfaction: a South African empirical study | Jason Cohen, Carlos Ferreira                                             | 2008 | SAICSIT                                      |
| P10| An empirical analysis of build failures in the continuous integra- tion workflows of Java-based open-source software | Stefan Schulte, Thomas Rausch, Waldemar Hummer, Philipp Leitner          | 2017 | MSR - International Conference on Mining Software Repositories |
| P11| An empirical study of activity, popularity, size, testing, and sta- bility in continuous integration | Saket Vishwasrao, Francisco Servant, Aakash Gautam                     | 2017 | MSR - International Conference on Mining Software Repositories |
| P12| An empirical study of the long duration of continuous integration builds | Ying Zou, Danel Atienca da Costa, Taher Ahmed Ghaleb                   | 2019 | Empirical Software Engineering              |
| P13| An empirical study of the personnel overhead of continuous integration | Shane McIntosh, Eduardo Coronado-Montoya, Marco Manglaviti, Kebeliya Gallaba | 2017 | MSR - International Conference on Mining Software Repositories |
| P14| Analyzing the effects of test driven development in GitHub           | Abram Hindle, Neil Borle, Meysam Feghhi, Eleni Stroulia, Russ Greiner   | 2018 | Empirical Software Engineering              |
| ID | Title                                                                 | Authors                                                                 | Year | Conference/Event                                |
|----|----------------------------------------------------------------------|------------------------------------------------------------------------|------|-----------------------------------------------|
| P15 | Analyzing the impact of social attributes on commit integration success | Mauricio Soto, Zack Coker, Claire Le Goues                              | 2017 | MSR - International Conference on Mining Software Repositories |
| P16 | Angry-builds: an empirical study of affect metrics and builds success on github ecosystem | Michele Marches, David Bowes, Giuseppe Desteфанis, Marco Ortu, Andrea Pinna, Roberto Tonelli | 2018 | Conference XP                                |
| P17 | Applying Continuous Integration for Reducing Web Applications Development Risks | Fang Yue Lei, Sen Tarning Lai                                            | 2015 | BWCCA - International Conference on Broadband and Wireless Computing, Communication and Applications |
| P18 | Automated reporting of anti-patterns and decay in continuous integration | Sebastian Proksch, Harald C. Gall, Massimiliano Di Penta, Carmine Vassallo | 2019 | ICSE - International Conference on Software Engineering |
| P19 | Automated software integration flows in industry: a multiple-case study | Daniel Stahl, Jan Bosch                                                  | 2014 | ICSSE - International Conference on Software Engineering |
| P20 | Build waiting time in continuous integration: an initial interdisciplinary literature review | Mika Manisty, Eero Laukkonen                                               | 2015 | ICSE - International Workshop on Rapid Continuous Software Engineering |
| P21 | Building lean continuous integration and delivery pipelines by applying DevOps principles: a case study at Varidesk | Vidroha Debroy, Seneca Miller, Lance Brimble                             | 2018 | ESSEC/PSE Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering |
| P22 | Building lean thinking in a telecom software development organization: strengths and challenges | Pasi Kuvaja, Pilar Rodriguez, Kirsii Mikkonen, Markku Oivo, Juan Garbajosa | 2013 | ICSSF - International Conference on Software and System Process |
| P23 | Built to last or built too fast? evaluating prediction models for build times | Ekaba Bisong, Eric Tran, Olga Baysal                                     | 2017 | MSR - International Conference on Mining Software Repositories |
| P24 | Challenges When Adopting Continuous Integration: A Case Study | Mikael Dienér, Richard Bernsson Svensson, Adam Debbiche                  | 2014 | International Conference on Product-Focused Software Process Improvement |
| P25 | Characterizing the influence of continuous integration: empirical results from 250+ open source and proprietary projects | Akond Rahman, Amritanshu Agrawal, Rahul Krishna, Alexander Sobran        | 2018 | SWAN - International Workshop on Software Analytics |
| P27 | Comparison of release engineering practices in a large mature company and a startup | Eero Laukkonen, Casper Lassenius, Juha Itkonen, Maria Paasivaara         | 2013 | Empirical Software Engineering |
| P28 | Continuous code quality: are we (really) doing that? | Alberto Bacchelli, Harold C. Gall, Fabio Palomba, Carmine Vassallo       | 2018 | ANSE - International Conference on Automated Software Engineering |
| P29 | Continuous Delivery Practices in a Large Financial Organization | Andy Zaidman, Carmine Vassallo, Fiorella Zampetti, Daniele Romano, Moritz Beller, Annibale Panichella, Massimiliano Di Penta | 2017 | ICSME - International Conference on Software Maintenance and Evolution |
| P30 | Continuous Delivery: Huge Benefits, but Challenges Too | Liaping Chen                                                              | 2015 | IEEE Software                                |
| P31 | Continuous Delivery? Easy! Just Change Everything (Well, Maybe It Is Not That Easy) | Steve Neely, Steve Stolt                                                  | 2013 | Agile Conference                              |
| P32 | Continuous deployment and schema evolution in SQL databases | Michael De Jong, Arie Van Deursen | 2015 | RELENG - International Workshop on Release Engineering |
| P33 | Continuous deployment at Facebook and OANDA | Michael Gentini, Kent Beck, Laurie Williams, Michael Stumm, Tony Savor, Mitchell Douglas | 2016 | ICSE - International Conference on Software Engineering |
| P34 | Continuous deployment of mobile software at Facebook (showcase) | Elisa Shibley, Chuck Ross, Kent Beck, Shi Su, Michael Stumm, Tony Savor | 2016 | ESEC/FSE Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering |
| P36 | Continuous Integration for HPC: Using Singularity and Jenkins | Zebula Sampeiro, Aaron Holt, Thomas Hauser | 2018 | PEARC - Practice and Experience on Advanced Research Computing |
| P37 | Continuous Integration and Quality Assurance: a case study of two open source projects | Jesper Holck, Niels Jørgensen | 2003 | Australasian Journal of Information Systems |
| P38 | Continuous Integration Applied to Software-Intensive Embedded Systems – Problems and Experiences | Torvald Mårtensson, Daniel Ståhl, Jan Bosch | 2016 | International Conference on Product-Focused Software Process Improvement |
| P39 | Continuous Integration for Web-Based Software Infrastructures: Lessons Learned on the webinos Project | John Lyle, Tao Su, Andrea Atzeni, Shamal Faily, Habib Virji, Christos Ntanos, Christos Botsikas | 2013 | Hata Verification Conference |
| P40 | Continuous Integration Impediments in Large-Scale Industry Projects | Torvald Mårtensson, Jan Bosch, Daniel Ståhl | 2017 | ICSA - IEEE International Conference on Software Architecture |
| P41 | Continuous Integration in a Social-Coding World: Empirical Evidence from GitHub | Boguslaw Vastescu, Mark G J Van Den Brand, Jules Wulms, Stef Van Schuylenburg, Alexander Serebrenik | 2014 | ICSEME - International Conference on Software Maintenance and Evolution |
| P42 | Continuous Integration in Open Source Software Development | Amit Deshpande, Dirk Riehle | 2008 | IFIP International Federation for Information Processing |
| P43 | Continuous Integration is Not About Build Systems | Torvald Mårtensson, Par Hansonstrom, Jan Bosch | 2017 | SEAA - Euromicro Conference on Software Engineering and Advanced Applications |
| P44 | Continuous Refactoring in CI: A Preliminary Study on the Perceived Advantages and Barriers | Carmine Vassallo, Fabio Palomba, Harald C. Gall | 2018 | ICSEME - International Conference on Software Maintenance and Evolution |
| P45 | Continuous software engineering and beyond: trends and challenges | Brian Fitzgerald, Klaas Jan Stol | 2014 | ICSEME - International Workshop on Rapid Continuous Software Engineering |
| P46 | Contrasting Big Bang with Continuous Integration Through Defect Reports | Daniel Levin, Ana Magazimous, Niklas Mellegard, Hakan Burden, Kenneth Lind | 2018 | IEEE Software |
| P47 | Determinants of pull-based development in the context of continuous integration | Cheng Yang, Huaamin Wang, Tao Wang, Gang Yin, Yue Yu | 2016 | Science China Information Sciences |
| P48 | DevOps: A Definition and Perceived Adoption Impediments | Kristian Nybom, Jens Smeds, Ivan Porres | 2015 | International Conference on Agile Software Development |
| P49 | Effect of Continuous Integration on Build Health in Undergraduate Team Projects | Suzanne M. Embury, Christopher Page | 2017 | Conference on Software Engineering Education and Training |
| P50 | Effectiveness of Test-Driven Development and Continuous Integration: A Case Study | Yoni Menuberg, Chintan Amrit | 2018 | IT Professional |
| P51 | Enabling Agile Testing through Continuous Integration | Sean Stolberg | 2009 | Agile Conference |
| P52 | Experienced benefits of continuous integration in industry software product development: A case study | Jan Bosch, Daniel Ståhl | 2013 | TASTED International Conference on Software Engineering |
| P53 | How does contributors’ involvement influence the build status of an open-source software project? | Renato O. Santos, Fernando Castor, Gustavo Pinto, Marcel Reboucas | 2017 | MSR - International Conference on Mining Software Repositories |
| P54 | How open source projects use static code analysis tools in continuous integration pipelines | Fiorella Zampetti, Rocco Oliveto, Gerardo Canfora, Massimiliano Di Penta, Simone Scalabrin | 2017 | MSR - International Conference on Mining Software Repositories |
| P55 | I’m leaving you, Travis: a continuous integration breakup story | Bogdan Vasescu, Christian Kästner, Michael Hilton, David Gray Widder | 2018 | ICSE - International Conference on Software Engineering |
| P56 | Impact of continuous integration on code reviews | Mohammad Masudur Rahman, Chanchal K. Roy | 2017 | MSR - International Conference on Mining Software Repositories |
| P57 | Implementation of a DevOps Pipeline for Serverless Applications | Vitalii Ivanov, Kari Smolander | 2018 | International Conference on Product-Focused Software Process Improvement |
| P58 | Inadequate testing, time pressure, and (over) confidence: a tale of continuous integration users | Marcel Reboucas, Gustavo Pinto, Fernando Castor | 2017 | CHANCE - International Workshop on Cooperative and Human Aspects of Software Engineering |
| P59 | Increasing quality and managing complexity in neuroinformatics software development with continuous integration | Yury V. Zaytsev, Abigail Morrison | 2013 | Frontiers in Neuroinformatics |
| P60 | Industry application of continuous integration modeling: a multiple-case study | Daniel Ståhl, Jan Bosch | 2016 | ICSE - International Conference on Software Engineering |
| P62 | Insights into continuous integration build failures | Md Rakibul Islam, Minhaz F. Zbran | 2017 | MSR - International Conference on Mining Software Repositories |
| P63 | ISM based identification of quality attributes for agile development | Partia Jain, Laxmi Ahuja, Arun Sharma | 2016 | International Conference on Reliability |
| P64 | It’s Not the Pants, it’s the People in the Pants Learnings from the Gap Agile Transformation – What Worked, How We Did it, and What Still Puzzles Us | David Goodman, Michael Elbaz | 2008 | Agile Conference |
| P65 | Lessons Learned: Using a Static Analysis Tool within a Continuous Integration System |  | 2016 | ISSREW - International Symposium on Software Reliability Engineering Workshops |
| P66 | Managing to release early, often and on time in the OpenStack software ecosystem | Jose Apolinaro Texeira, Helena Karsten | 2019 | Journal of Internet Services and Applications |
| ID | Title                                                                 | Authors                                                                 | Year | Conference/Journal                                                                 |
|----|----------------------------------------------------------------------|------------------------------------------------------------------------|------|-----------------------------------------------------------------------------------|
| P67| Measurement and Impact Factors of Speed of Reviews and Integration in Continuous Software Engineering | Wilhelm Meding, Ola Söder, Magnus Bäck, Miroslaw Staron               | 2018 | Foundations of Computing and Decision Sciences                                       |
| P69| Moving from Closed to Open Source: Observations from Six Transitioned Projects to GitHub | Pavneet Singh Kochhar, Nachiappan Nagappan, Eirini Kallianvakou, Christian Bird, Thomas Zimmermann | 2019 | IEEE Transactions on Software Engineering                                            |
| P70| On the interplay between non-functional requirements and builds on continuous integration | Marcelo De A. Maia, Cécia Z. Felicio, Klerisson V.R. Paixao, Fernanda M. Delfim | 2017 | MSR - International Conference on Mining Software Repositories                       |
| P71| On the journey to continuous deployment: Technical and social challenges along the way | Gerry Gerard Claps, Richard Bertisson Svensson, Aybuke Aurum             | 2015 | Information and Software Technology                                                  |
| P72| Oops, my tests broke the build: an explorative analysis of Travis CI with GitHub | Moritz Beller, Andy Zaidman, Georgios Gousios                           | 2017 | MSR - International Conference on Mining Software Repositories                       |
| P73| Practitioners' eye on continuous software engineering: An interview study | Jan Ole Johanssen, Anja Kleebaum, Bernd Bruegge, Barbara Paech          | 2018 | ICSSP - International Conference on Software and System Process                      |
| P74| Quality and productivity outcomes relating to continuous integration in GitHub | Vladimir Filkov, Bogdan Vasilescu, Yue Yu, Huaimin Wang, Premkumar Devanbu | 2015 | ESEC/FSE Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering |
| P75| Scaling Continuous Integration | R. Owen Rogers                                                   | 2004 | International Conference on Extreme Programming and Agile Processes in Software Engineering |
| P76| Screening heuristics for project gating systems | Edi Shmuelt, Zahi Volf                                             | 2017 | ESEC/FSE Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering |
| P77| Sentiment analysis of Travis CI builds | Bruno Silva, Rodrigo Souza                                         | 2017 | MSR - International Conference on Mining Software Repositories                       |
| P78| Software artefacts consistency management towards continuous integration: A roadmap | I. Perera, D. A. Meedeniya, I. D. Rubasinghe                         | 2019 | International Journal of Advanced Computer Science and Applications                 |
| P79| Software Quality Improvement Practices in Continuous Integration | Selin Aydin, Ilgi Keskin Kaynak, Evren Cilden                        | 2019 | European Conference on Software Process Improvement                                  |
| P80| Stakeholder Perceptions of the Adoption of Continuous Integration – A Case Study | Marta Paasivaara, Teemu Arvonen, Eero Laukkanen                   | 2015 | Agile Conference                                                                   |
| P81| Studying the impact of adopting continuous integration on the delivery time of pull requests | Joao Helis Bernardo, Uirá Kulesza, Daniel Alencar da Costa           | 2018 | ICSE - International Conference on Software Engineering                              |
| P82| Successful extreme programming: Fidelity to the methodology or good teamwork? | Stephen Wood, George Michaelides, Chris Thomson                     | 2013 | Information and Software Technology                                                  |
| P83| Synthesizing Continuous Deployment Practices Used in Software Development | Chris Parnin, Akond Rahman, Eric Helms, Laurie Williams              | 2015 | Agile Conference                                                                   |
| P84| Team Pace Keeping Build Times Down | Graham Brooks                                                      | 2008 | Agile Conference                                                                   |
| P85 | Test activities in the continuous integration and delivery pipeline | Daniel Ståhl, Torvald Mårtensson, Jan Bosch | 2019 | Journal of Software: Evolution and Process |
| P86 | The continuity of continuous integration: Correlations and consequences | Jan Bosch, Torvald Mårtensson, Daniel Ståhl | 2017 | Journal of Systems and Software |
| P87 | The effects of individual XP practices on software development effort | Paul Rodrigues, Prakash Ramaswamy, Ś Kuppuswami, K Vivekanandan | 2003 | ACM SIGSOFT Software Engineering Notes |
| P88 | The highways and country roads to continuous deployment | Marko Leppanen, Miika V Mäntylä, Juha Ikkonen, Veli-Pekka Eloranta, Max Pagels, Simo Mäkinen, Toni Männistö | 2015 | IEEE Software |
| P89 | The impact of continuous integration on other software development practices: a large-scale empirical study | Vladimir Filkov, Yuming Zhou, Alexander Serebrenik, Yangyang Zhao, Bogdan Vasilescu | 2017 | ASE - International Conference on Automated Software Engineering |
| P90 | The impact of the adoption of continuous integration on developer attraction and retention | Keheliya Gallaba, Yash Gupta, Yusaira Khan, Shane McIntosh | 2017 | MSR - International Conference on Mining Software Repositories |
| P91 | The links between agile practices, interpersonal conflict, and perceived productivity | Lucas Gren | 2017 | EASE - Conference on Evaluation and Assessment in Software Engineering |
| P92 | An empirical study examining the usage and perceived importance of XP practices | Jessica Zhang, Ann Fruhling | 2007 | AMCIS - Americas Conference on Information Systems |
| P93 | The Tarpt – A general theory of software engineering | Pontus Johnson, Mathias Ekstedt | 2016 | Information and Software Technology |
| P94 | Towards Agile Testing for Railway Safety-critical Software | Jin Guo, Yaxin Cao, Chang Rao, Yao Li, Nan Li, Jeff Lei | 2016 | Conference XP |
| P95 | Towards Architecting for Continuous Delivery | Lianping Chen | 2015 | ICSA - IEEE International Conference on Software Architecture |
| P96 | Towards quality gates in continuous delivery and deployment | Gerald Schermann, Jürgen Cito, Harald C. Gail, Philipp Leitner | 2016 | ICPC |
| P97 | Trade-offs in continuous integration: assurance, security, and flexibility | Danny Dig, Michael Hilton, Nicholas Nelson, Timothy Tunnell, Darko Marinov | 2017 | ESEC/FSE Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering |
| P98 | Transparency and contracts: continuous integration and delivery in the automotive ecosystem | Eric Knauss, Rob Van Der Valk, Patrizio Pelliccione, Rogardt Heldal, Patricia Lago, Jacob Juul | 2018 | ICSE - International Conference on Software Engineering |
| P99 | Understanding similarities and differences in software development practices across domains | Pozayn Jamsibh, Christian Kästner, Markus Viggiano, Eduardo Figueiredo, Johnatan Oliveira | 2018 | ICGSE - International Conference on Global Software Engineering |
| P100 | Usage, costs, and benefits of continuous integration in open-source projects | Timothy Tunnell, Michael Hilton, Kai Huang, Darko Marinov, Danny Dig | 2016 | ASE - International Conference on Automated Software Engineering |
| P101 | Use and Misuse of Continuous Integration Features: An Empirical Study of Projects that (mis)use Travis CI | Keheliya Gallaba, Shane McIntosh | 2018 | IEEE Transactions on Software Engineering |
| P102 | Using continuous integration and automated test techniques for a robust C4ISR system | Eray Tüzün, Erdoğan Geler, H. Mehmet Yüksel, Emrah Boykili, Buyurman Baykal | 2009 | ICSIS - International Symposium on Computer and Information Sciences |
| P103 | Vulnerabilities in Continuous Delivery Pipelines? A Case Study | Christina Paule, Thomas F. Dullmann, Andre Van Hoorn | 2019 | ICSA - IEEE International Conference on Software Architecture |
| P104 | Wait for it: determinants of pull request evaluation latency on GitHub | Yue Yu, Bogdan Vasilescu, Premkumar Devanbu, Vladimir Filkov, Huaimin Wang | 2015 | MSR - International Conference on Mining Software Repositories |
| P105 | Why modern open source projects fail | Jailton Coelho, Marco Tulio Valente | 2017 | ESEC/FSE Joint Meeting European Software Engineering Conference and Symposium on the Foundations of Software Engineering |
| P106 | Work practices and challenges in continuous integration: A survey with Travis CI users | Rodrigo Bonifacio, Marcel Reboucas, Gustavo Pinto, Fernando Castor | 2018 | Software - Practice and Experience |

Table 22: Primary Studies selected in the review.