

Software Startup Engineering: A Systematic Mapping Study

Vebjørn Berg^a, Jørgen Birkeland^a, Anh Nguyen-Duc^b, Ilias Pappas^a, Letizia Jaccheri^a

^a*Department of Computer Science, Norwegian University of Science and Technology
Sem Sælands vei 9, 7034 Trondheim, Norway*

^b*Department of Business and IT, University of South-Eastern Norway
Lærerskoleveien 40, 3679 Notodden, Norway*

Abstract

[Context] Software startups have long been a significant driver in economic growth and innovation. The on-going failure of the major number of startups calls for a better understanding of state-of-the-practice of startup activities. [Objective] With a focus on engineering perspective, this study aims at identifying the change in focus of research area and thematic concepts operating startup research. [Method] A systematic mapping study on 74 primary papers (in which 27 papers are newly selected) from 1994 to 2017 was conducted with a comparison with findings from previous mapping studies. A classification schema was developed, and the primary studies were ranked according to their rigour. [Results] We discovered that most research has been conducted within the SWEBOK knowledge areas software engineering process, management, construction, design, and requirements, with the shift of focus towards process and management areas. We also provide an alternative classification for future startup research. We find that the rigour of the primary papers was assessed to be higher between 2013-2017 than that of 1994-2013. We also find an inconsistency of characterizing startups. [Conclusions] Future work can focus on certain research themes, such as startup evolution models and human aspects, and consolidate the thematic concepts describing software startups.

Keywords: Software development, Systematic mapping study, Startup, Software startup, Software engineering

Email addresses: vebjoern.berg@gmail.com (Vebjørn Berg),
jorgen.birkeland1@gmail.com (Jørgen Birkeland), anh.nguyen.duc@usn.no (Anh Nguyen-Duc), ilpappas@ntnu.no (Ilias Pappas), letizia.jaccheri@ntnu.no (Letizia Jaccheri), vebjorbe@stud.ntnu.no, jorgebi@stud.ntnu.no (Letizia Jaccheri)

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1. Introduction

Technology-based startups have long been an important driver for global economic growth and competitiveness [1]. Software startups, newly created companies producing cutting-edge software technology, have shown to be an important source of software innovation. Despite stories of successful startups, 90 percent of them fail, primarily due to self-destruction rather than competition [2, 3]. The failures come from financial and market factors, for example, insufficient funding to operate startups activities, failure in finding product-market fit, and building an entrepreneurial team [4]. However, there are also identified unique challenges related to software development and innovation methods [4]. Software startup engineering can be defined as "the use of scientific, engineering, managerial, and systematic approaches with the aim of successfully developing software systems in startup companies" [5]. Startup researchers have called for a further attention to engineering approaches to support startup activities in all startup evolution stages [1]. Previously, most of the research in the field of software engineering has been conducted in relation to the needs and challenges of established companies, first identified by Sutton [6].

Startups are at the forefront of applying new technologies in practice. From an engineering perspective, developing technology products is challenging as the startup context presents a dynamic and fast-changed environment, making it difficult to adopt prescriptive engineering practices [5]. Despite the rapid growth of the population of startups, the research on software engineering in startups is still at an early stage [1].

One of the most extensive literature reviews in the field is the systematic mapping study of Paternoster et al. [7], reviewing a total of 43 primary studies from 1994 until 2013. This review shows a lack of high quality studies in the field. While a large amount of Software Engineering practices were extracted from startups, the practices were chosen randomly and adopted under the constraints imposed by the startup context. Thus, an updated systematic mapping is required as it will identify the current status in the area and pave the way for more empirical studies examining startups.

Since 2015, we observed an increased focus on software startup research (i.e., the organization of three International software startup workshops (ISSW) in 2016 and 2017, and software startups tracks at PROFES 2017 and XP 2017 conferences). The previous systematic review has rapidly gained a large amount of citations [7]. While this implies the further growth in software startup research, a revisit on the area can identify how engineering activities in software startups have changed over time. The objective of this mapping study is to provide an updated view on software startup research in order to identify research gaps. Different from the previous mapping studies [7, 8], we aim at synthesizing startup descriptions in research and its associated software engineering knowledge areas. Beside market factors and financial factors, knowledge about engineering factors and how they affect the startup initiatives and development would be helpful for entrepreneurs in understanding their startups' challenges.

We assume that startups perform various types of software engineering ac-

tivities, as described in SWEBOK [9]. We would like to observe how software startup research has evolved and possibly matured in some Software Engineering knowledge areas. SWEBOK is previously used in Klotins et al. [8], which allow for easy comparisons and make it possible to identify changes in terms of research direction for the last five years.

The research objective leads to the following research questions:

RQ1: How has software startup research changed over time in terms of focused knowledge areas?

RQ2: What is the relative strength of the empirical evidence reported?

55 RQ3: In what context has software startup research been conducted?

In this article, we present results from systematic mapping studies of software startup research from 1994 to 2017. To do so, we expand previous literature [7, 8] with the focus on papers published from 2013-2017. We found 27 relevant articles during the last five years. The results were merged and compared to the previous mapping studies. To address RQ1, the papers were structured according to the knowledge areas identified in SWEBOK [9]. With RQ2, we evaluated the papers' rigour to compare the quality of papers published before and after 2013. Finally, with RQ3, we examined to what extent the retrieved papers provided sufficient startup descriptions, and if there were similarities in the use of terms describing the startup context between the papers. Our meta-analysis on Software Engineering knowledge area and startup case context reveals important areas for investigation. We also come up with a classification of future research on software startups.

The contribution of this mapping study is two-fold. Firstly, the study provides a comprehensive view of software startup for Software Engineering researchers. Possible research gap is derived for future study. Secondly, the study provides a map of the contextual setting of investigated startups. Contextual map infers the applicability area of empirical findings from the startups. This would help to compare and to generalize future research in software startups.

75 The paper proceeds as follows: Section 2 introduces the background of the study and the related mapping studies. Section 3 presents the research method undertaken and threats to the validity of the mapping study. Section 4 reports the results and visualizes both our findings and the findings of the previous mapping studies. Section 5 discusses the results in relation to the research questions. Section 6 concludes the paper by answering the research questions and presents implications and future work.

2. Background

2.1. Software startups

85 A startup can be defined as “an organization that is challenged by youth and immaturity, with extremely limited resources, multiple influences, and dynamic technologies and markets” [6]. More specifically, Coleman and O’Connor [10] describe software startups as “unique companies that develop software through

various processes and without a prescriptive methodology”. Others have characterized software startups as modern organizations with little or no operating history, aiming at developing high-tech and innovative products, and rapidly scale their business in extremely dynamic markets [11].

Software startups develop innovative software products in environments of time-pressure and a lack of resources, constantly searching for sustainable and scalable business models. This is in contrast to established companies, that have more resources and already command a mature market [1]. While established companies focus on optimizing an existing business model, startups focus on finding one, which requires experimentation of various products in different markets [12]. Instead of developing software for a specific client, software startups develop systems which have market-driven requirements, meaning they have no specific customers before their product is released [13, 14].

There exist many processes to manage product development (i.e., processes concerned with *how* to develop a product), like agile and waterfall methods. (e.g., agile and waterfall). However, these processes do not focus on addressing *what* product to develop, which is essential in the startup context where both problems and solutions tend to be poorly understood [15]. The high failure rates of software startups are often caused by a lack of customers rather than product development issues [2, 13].

2.2. Startup Development Methodology

Software startups generally develop products in high-potential target markets [16], without necessarily knowing *what* the customers want [14]. This relates to market-driven software development, which emphasizes the importance of specific requirement elicitation techniques (e.g., prototyping), and time-to-market as key strategic objectives [14, 17]. In a market-driven context, requirements tend to be (1) invented by the software company, (2) rarely documented [18], and (3) validated only after the product is released in the market [14, 19, 20, 21]. As to this, products that don’t meet customer needs are common, resulting in failure of new product releases [22]. Entrepreneurial and customer focused development approaches like [23, 24, 25, 26] have received attention from the research community. The customer development process introduced by Blank [23] can be divided into four phases: (1) customer discovery, (2) customer validation, (3) customer creation, and (4) company building. A frequently applied entrepreneurship theory among entrepreneurs is Lean Startup, which builds on the principles from Blank. The method has been criticized by researchers for being based on personal experience and opinions rather than empirical evidence, however, concepts from the Lean Startup have attracted considerable attention among practitioners [15, 16].

2.2.1. Lean Startup

Ries [12] presented the Lean Startup method in 2008, based on lean principles first introduced by Toyota [27]. The method aims at creating and managing startups, to deliver products or services to customers as fast as possible. The

method provides principles for how to run a new business, where the goal is to grow the business with maximum acceleration. By iteratively turning ideas into products, measure customers' satisfiability, and learn from their feedback, startups can accelerate their business. This process is referred to as the build-measure-learn (BML) feedback loop, which is an iterative process, where the goal is to minimize the total time through the loop.

Key to the BML feedback loop is to do continuous experimentation on customers to test hypotheses. The hypotheses can be tested by building a minimum viable product (MVP), which is the simplest form of an idea, product, or service that can answer the hypotheses. Any feature, process, or effort not directly contributing to answering the hypotheses, is removed. The aim is to eliminate any waste throughout the process. Empirical research has found three main types of MVP usage, including (1) MVP as a design artifact, (2) MVP as a boundary-spanning object, and (3) MVP as a reusable artifact [28]. MVPs can be used to bridge knowledge gaps within organizations or to provide a mutual understanding between customer input and product design.

When the MVP has been built and the hypotheses tested, the next step is to measure the customer feedback and learn from it. This is referred to as validated learning, which is about learning which efforts are value-creating and eliminate the efforts that aren't necessary for learning customer needs. The final step of the loop is whether to pivot or persevere. A pivot is a structured course correction designed to test a new fundamental hypothesis about the product, strategy, and engine of growth [12]. Bajwa et al. [29] identified 10 pivot types and 14 triggering factors, concluding that trying to solve the wrong problem for the customer is the most common reason for pivoting (i.e., customer need pivot). If a pivot isn't required, meaning the MVP was found to be fit to market, the startup perseveres. The BML feedback loop then continues, where new hypotheses are tested and measured.

The Lean Startup method is beneficial for business development and understanding *what* product to develop, emphasizing the importance of getting the product to customers as soon as possible. Startups tend to prefer time and cost over product quality [30], neglecting traditional process activities like formal project management, documentation, and testing [5]. Shortcuts taken in product quality, design, or infrastructure can eventually inhibit learning and customer satisfaction [12]. Software startups need their own development practices to manage the challenges posed by customer development methods such as Lean Startup.

2.3. Software Engineering in Startups

Software startup engineering can be defined as “the use of scientific, engineering, managerial, and systematic approaches with the aim of successfully developing software systems in startup companies” [5]. The degree of process in software development is dependent on system complexity, business risk, and the number of people involved [31]. The impact of the inadequate use of software engineering practices might be a significant factor leading to the high failure rates [8]. As time and resources are extremely scarce in environments of high

market and technology uncertainty, software startups need effective practices to face those unique challenges [11]. The need for process depends on the lifecycle stage of the company, divided into four stages [3].

- 180 • Stage 1: The startup stage is defined as the time from idea conceptualization to the first sale. A small executive team with necessary skills is required in order to build the product.
- Stage 2: The stabilization phase lasts until the product is stable enough to be commissioned to a new customer without causing any overhead on product development.
- 185 • Stage 3: The growth phase begins with a stable product development process and lasts until market size, share, and growth rate have been established.
- Stage 4: The last stage is when the startup has evolved into a mature organization. The product development is robust and easy to predict,
190 with proven processes for new product inventions.

Startups are creative and flexible by nature, and so strict release processes are often overshadowed by quick, inexpensive product releases, with focus on customer acquisition [31]. This can often result in ineffective software engineering practices [6]. Since startups have limited resources, the focus is often
195 directed towards product development, rather than focusing on the establishment of rigid processes [10].

It is important to notice that in terms of communication and cooperation dynamics, startups and established companies have different software engineering experiences and needs [30]. While established companies have well-defined
200 processes for their business, startups usually have low-ceremony processes [32], which means that the amount of management overhead is low. Instead of utilizing repeatable and controlled processes, startups take advantage of reactive and low-precision engineering practices with a focus on the productivity and freedom of their teams [33, 34, 35].

205 Reactive, low-ceremony processes are powerful in the early stages of software development since speed and learning are important [12]. However, as startups enter new lifecycle stages, an increased usage of processes for addressing key customer needs, delivering functional code early and often, and providing a good user experience is required [32]. New business issues like hiring, sales, and funding appear, and more users and complex code require an extended focus
210 on robustness, scalability, performance, and power consumption [31]. The use of methods like the Lean Startup is one of the reasons why software startups need and sometimes apply their own software engineering practices, which pose challenges when it comes to software engineering. Lean Startup is beneficial for
215 business and product development, but when it comes to software development, a more hybrid approach of agile and lean may provide the most benefits in terms of cost, time, quality, and scope [30].

2.4. Existing literature reviews

Since the gap in research specific to software engineering in startups first
220 was identified [6], there have only been undertaken two mapping studies entirely
dedicated to the research area [7, 8]. There also exist relevant work related to
SMEs (small and medium-sized enterprises) [36], and VSEs (very small entities),
which become more relevant as startups enter more mature lifecycle stages,
however, the early stages of startups pose some specific challenges and needs
225 (e.g., little working/operating history).

The first systematic mapping by Paternoster et al. [7] covered studies up
to December 2013, aiming at structuring and analyzing state-of-the-art on soft-
ware startup research. The conclusion of the paper is that there existed few
high-quality studies contributing to the body of knowledge and that there is
230 a need for more studies supporting startups for all lifecycle stages. From a
total of 43 primary studies, only 4 papers [10, 37, 38, 39] were considered as
strong contributions and entirely dedicated to software engineering activities in
startups. The results showed that startups choose their software engineering
practices opportunistically, and adapt them to their own context.

235 Klotins et al. [8] conducted a mapping study published in 2015, classifying
14 primary studies on software startup engineering into 11 of 15 SWEBOK
knowledge areas. The paper concludes as Paternoster et al. [7], that research
did not provide support for any challenges or engineering practices in startups,
and that available research results were hard to transfer between startups due
240 to low rigour. This was explained by the lack of contextual information in the
studies, and how the studies were performed.

3. Research Methodology

A systematic mapping study was undertaken to provide an overview of the
research available in the field of software engineering specific to startups, fol-
245 lowing guidelines from Kitchenham [40] and several steps of the standardized
process for systematic mapping studies, as illustrated in figure 1 [41].

Systematic mapping studies can be used in research areas with few relevant
primary studies of high quality, as they provide a coarse-grained overview of the
publications within the topic area [41]. This systematic mapping study covers
250 74 primary papers, extending the two previous mapping studies [7, 8]. As these
studies only cover three papers from 2013, the search strategy of this systematic
mapping study included papers from 2013 up to October 2017. This approach
allowed for merging and comparing the primary literature within the research
field for the period 1994-2017.

255 The main steps of our process are illustrated in figure 1, and include the
search and study selection strategies, manual search, data extraction, quality
assessment, and the data synthesis method. The process led to a total number
of 27 new primary papers found in table A.7.

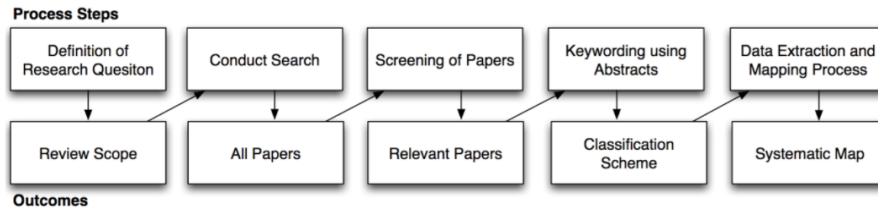


Figure 1: The Systematic Mapping Study Process [41]

3.1. Mapping Procedure

260 *Step 1: Pilot search.* Pilot searches were performed in online databases to find an optimal search string and the most suitable databases. The searches helped to define the criteria for inclusion and quality assessment and the classification schema.

265 *Step 2: Search strategy and study selection.* Based on the search string, a total number of 1012 unduplicated papers were retrieved. This was further limited to 74 (titles), 28 (abstracts), and finally, 20 papers after a collaborate effort from the first and second author was conducted. The full-text of the remaining 20 papers was read.

270 *Step 3: Additional manual search.* A manual search was performed to find more relevant papers. The publication lists of relevant authors were scanned, and the forward snowballing technique was used [42]. For the forward snowballing, Google Scholar was used to examining the citations of the papers retrieved. This resulted in seven more relevant papers. These were either not published in the databases, or were overlooked in step 2.

275 *Step 4: Quality assessment.* To identify the rigour of the remaining papers, a quality assessment was performed on the papers that provided empirical evidence. The complete assessment can be found in table B.10.

280 *Step 5: Data extraction and synthesis.* From the primary papers, relevant data and information were extracted into a classification schema. A multi-step synthesis was performed to answer the research questions.

3.2. Data Sources and Search Strategy

The systematic search strategy consisted of searches in three online bibliographic databases. The databases were selected from their ability to handle complex search strings, their general use in similar literature reviews in the software engineering community [7, 36], and the fact that they index the research articles from other databases. In addition, to ensure the best possible coverage of the literature, we performed complementary searches and forward snowballing (section 3.4 Manual Search). Following guidelines from Wohlin [42], systematic

literature studies should use a combination of approaches for identifying relevant literature, where forward snowballing is found particularly useful. Forward snowballing can reduce systematic errors related to the selection of databases and construction of the search string [42]. To obtain high-quality data, the following databases were used:

Database	Papers
Scopus	451
ISI Web of Science	121
Engineering Village Compendex	875
Total	1447

Table 1: The searched databases and number of retrievals

Initial searches in the databases were conducted to identify keywords related to software engineering and startups, targeting title, abstract, and keywords. The most frequently used keywords for “startup” were chosen and combined in the search string [7]. The final search string consisted of several search terms combined using the Boolean operator “OR”:

“(startups OR start-up OR startup) AND software engineering OR (startups OR start-up OR startup) AND software development OR (startups OR start-up OR startup) AND software AND agile OR (startups OR start-up OR startup) AND software process OR (startups OR start-up OR startup) AND software tools”.

3.3. Study Selection

The study selection process is illustrated in figure 2, along with the number of papers at each stage. Searching the databases Scopus, ISI Web of Science, and Engineering Village using the search string returned 1447 papers, resulting in 1012 unduplicated studies. The searches targeted the document types: book chapters, journal article, conference article, conference proceedings, dissertation, and report chapters.

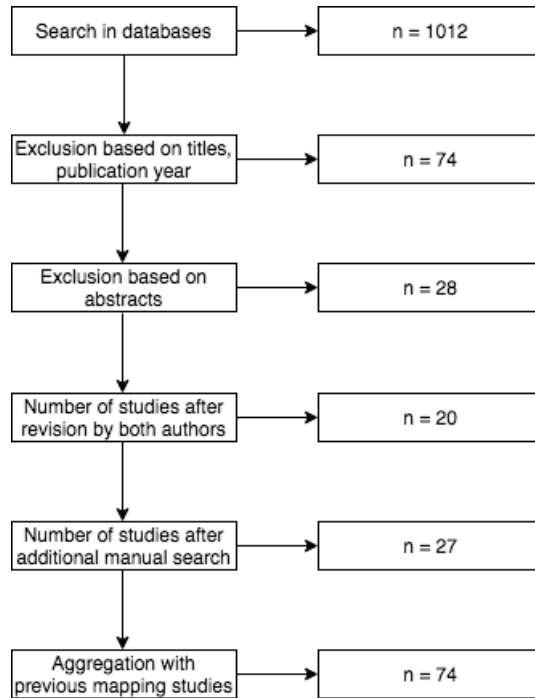


Figure 2: The Study Selection Process

Papers were relevant for inclusion in the study if they met the following criteria: (1) investigate concepts/problems/solutions of engineering in software startups, (2) present contributions in the form of lessons learned, framework, guidelines, theory, tool, model, or advice as applied in Paternoster et al. [7], (3) are not included in any of the previous mapping studies, and (4) studies are written in English. The papers that were selected are scientific peer-reviewed articles, which is independent of the role of authors. We did not find experience reports from entrepreneurs, which might make the sample of papers lean towards the researcher community. To decrease the number of papers into a manageable amount, workshops, and papers based on expert opinion were excluded from the review process.

As common for systematic mapping studies [41], this study focuses on synthesizing empirical research. Empirical studies are important for evidence-based software engineering research and practice, and for generating a knowledge base leading to accepted and well-formed theories [40, 43]. This study provides an overview of empirical research on software startup engineering to date, and how research has evolved and possibly matured over the time period.

The retrieved papers were examined by the first and second author, where each author separately reviewed the papers based on titles and abstracts. Disagreements were resolved by discussing the full text of the relevant papers. This was necessary as some of the abstracts were incomplete or poor. At this stage

another 8 papers were excluded, making the total of newly selected papers 20, before performing the additional manual search.

3.4. Manual Search

335 A manual search was conducted with the participation of the third author, using the forward snowballing technique [42], to identify additional papers not discovered by the search string. Google Scholar was used to examine the citations to the paper being examined. The publication lists of frequently appearing authors were also searched. This resulted in several papers as candidates for
340 inclusion. After assessing title, abstract, and finally the full text, 7 more papers were included as primary studies [17, 28, 29, 44, 45, 46, 47]. Among the papers, 21 were conference papers, five were journal papers, and one was a book chapter.

3.5. Quality Assessment

345 To build on previous work, a quality assessment of the new primary papers providing empirical evidence was performed. The total number of eligible papers was 22 (table A.7). Although systematic mapping studies usually don't evaluate the quality of each paper in such depth as systematic literature reviews, the quality assessment process was undertaken to assess how results were presented in the primary studies. No paper was excluded based on the quality assessment.

350 To assess the rigour, credibility, and relevance of the papers, we adopted the quality assessment scheme from Nguyen-Duc et al. [48]. Quality assessment has been identified as important for performing empirical research in software engineering [40, 49]. Table 2 illustrates 10 quality evaluation criteria. For each criterion the papers met, they got a score of 1, and otherwise 0. This means
355 that the maximum score a paper could get was 10. A score of 0-3 was regarded as low rigour, 4-6 medium rigour, and 7-10 high rigour. The complete quality assessment can be found in table B.10.

Problem Statement

Q1. Is research objective sufficiently explained and well-motivated?

Research Design

Q2. Is the context of study clearly stated?

Q3. Is the research design prepared sufficiently?

Data collection

Q4. Are the data collection & measures adequately described?

Q5. Are the measures and constructs used in the study the most relevant for answering the research question?

Data analysis

Q6. Is the data analysis used in the study adequately described?

Q7a. Qualitative study: Are the interpretation of evidences clearly described?

Q7b. Quantitative study: Are the effect size reported with assessed statistical significance?

Q8. Are potential alternative explanations considered and discussed in the analysis?

Conclusion

Q9. Are the findings of study clearly stated and supported by the results?

Q10. Does the paper discuss limitations or validity?

Table 2: Quality Assessment Checklist [48]

3.6. Data Extraction and Synthesis

After the quality assessment, we defined the classification schema (table A.7).
360 Data from each of the 27 newly selected primary studies were then systematically extracted into the classification schema, according to the predetermined attributes: (1) SWEBOK knowledge area, (2) Research method, (3) Contribution type, (4) Pertinence, (5) Term for “startup”, (6) Incubator context, (7) Publisher. The chosen attributes were inspired by previous mapping studies
365 [7, 8, 36], and from the process of finding keywords in the abstracts of the retrieved papers [41]. Organizing the findings into tabular form enabled for easy comparisons across studies and time periods. In addition to classifying the papers, each paper was scanned for thematic concepts to identify researchers’ descriptions of investigated startups. The thematic concepts were adopted from
370 the recurring themes found in Paternoster et al. [7]. This made it possible to assess the agreement in the community to the definition of startups.

The software engineering book of knowledge (SWEBOK) was created to provide a consistent view of software engineering, and to set the boundary of software engineering with respect to other disciplines [9]. SWEBOK contains
375 15 knowledge areas that characterize the practice of software engineering. The focal point of the paper is to propose research directions based on the knowledge areas following the work done by existing literature. Since the two major mapping studies in the area follow different approaches, that is SWEBOK [8] and focus facets [7], in the present study we focus on KAs, as this can allow the

380 reader to better comprehend how the two different approaches are connected,
thus offering a more holistic understanding of the current status in software
startup engineering research. Assigning each paper into the specific knowledge
areas was done by the first and second author. Two researchers read the titles,
keywords, abstracts, and the body of each paper, before evaluating the papers'
385 conformance with each specific knowledge area's description or subareas.

3.7. Threats to Validity

There are several threats to the validity of systematic mapping studies [50].
One threat is related to the data extraction from each paper, where results
can be biased from researchers personal judgment. To mitigate this threat,
390 and ensure correct classification of each paper into the SWEBOK knowledge
areas, this process was performed jointly by the first and second author at one
computer, resolving any conflicts and regulating individual bias.

Threats to the retrieval of relevant papers must also be considered. The
inconsistent use of terms for "startup" made it difficult to cover all used terms
395 in the search string. Hence, it appeared terms not considered when constructing
the search string. Some of these were "founder teams", "very small enterprise",
"very small entity", and "very small company", which all were used in relation
to the startup context. Relevant papers might therefore have been overlooked.

The use of only three bibliographic databases might have affected the number
400 of relevant papers retrieved. Compared to the number of databases used in
similar studies, this seems to be at the low-end. The chosen databases are
however among the most used ones in the field of software engineering, and the
databases that contributed to the most retrieved papers in other studies [7].
The risk of missing papers published the last five years was mitigated by the
405 use of forward snowballing which lead to the retrieval of seven more papers.

To make sure the study selection was not biased from personal opinions,
paper selection involved the first, second, and third author of the paper, which
allowed a collaborative resolution of conflicting views, following guidelines from
Kitchenham [40]. We defined clear inclusion and exclusion criteria, and a quality
410 assessment checklist to assess each paper's quality. Disagreement to quality
assessment was discussed between author one and two until consensus was reached.
This decreased the risk of miss-classifying any relevant papers.

For the quality assessment, we only used two points to collect answers, as the
first and second author were unfamiliar with the research field. The papers got
415 a score of 1 if they met the criteria, and otherwise 0. Prior studies have used a
more fine-grained classification of quality criteria and even used different criteria
in some occasions. It is more likely that the papers in our study obtained higher
rigour than they would have received if another more fine-grained assessment
method had been used.

420 **4. Results**

This section presents the extracted data of the primary studies. The section
is divided into the three research questions to allow for better visualization and

presentation of the most relevant findings. The final number of primary papers ended up being 74, adding the 27 new papers to the existing 44.

425 *4.1. RQ1: How has software startup research changed over time in terms of
focused knowledge areas?*

This section is divided into two sub-sections. Section 4.1.1 presents the publication frequency of primary studies from 1994-2017. Section 4.1.2 presents the SWEBOK knowledge areas, contribution types, and empirical evidence between
430 1994-2017.

4.1.1. Publication Frequency

Figure 3 shows the number of studies published in relation to software startup engineering between 1994-2017, constituting a total of 74 published papers. We observe that the publication frequency of papers between 2013-2017 is higher than for any period before 2013. From 1994-2013, the highest number of primary papers within a single year was 7 (2008). In comparison, 2016 and 2017 constituted 9 and 11 papers respectively. The pertinence of the papers published between 2013-2017 was generally higher than what was found for the period 1994-2013. 85 percent of the papers from 2013-2017 had high pertinence, meaning that they were entirely dedicated to software engineering activities in startups. The remaining four papers were focusing on activities of small software companies, and so set to partial pertinence (table A.7). Although their focus was not entirely dedicated to startups, some of them 51 performed empirical studies on startups, referring to them as “very small entities” or “small software companies”. In the period 1994-2013, 57 percent of the papers had high pertinence, while 20 percent had partial pertinence.
440

445 Klotins et al. 8 only includes 4 unique primary papers 52, 53, 54, 55, as the remaining 10 papers were included among the 43 primary papers in Paternoster et al. 7. The 4 papers are from 1994, 2000, 2008, and 2013.

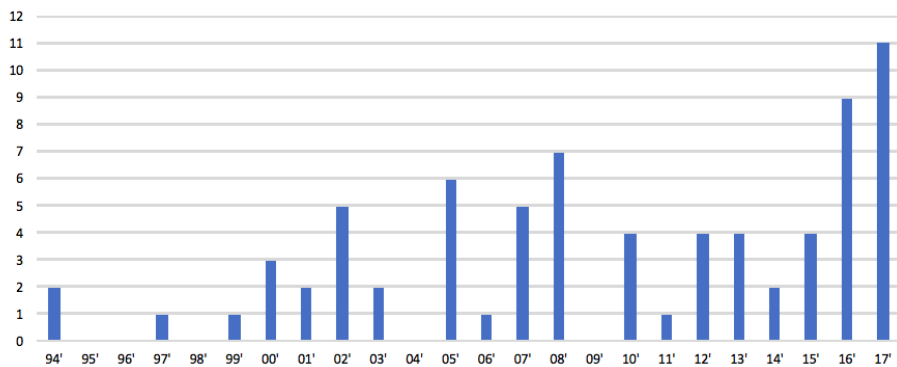


Figure 3: Publication Frequency, 1994-2017

450 4.1.2. Knowledge Areas

The 27 new primary studies were classified into the knowledge areas of SWE-BOK [9]. The categories were developed by the software community as a baseline for the body of knowledge within software engineering. Figure 4 illustrates what knowledge areas that have received most attention the last five years, and to what extent empirical studies have been undertaken. The figure shows which research methods that have been used to address each of the knowledge areas. Only the papers providing empirical evidence (22 papers) were included in the figure, covering a total of 9 knowledge areas. Some of the papers covered one or more knowledge areas (e.g., Nguyen-Duc et al. [56]).

460 The assessed research methods followed guidelines from Oates [57], and include (1) survey, (2) design and creation, (3) experiment, (4) case study, (5) action research, and (6) ethnography (table A.8). Case study was the most frequently used empirical research method (81 percent), followed by experiments (10 percent), surveys (6 percent), and design and creation (3 percent). Action research and ethnography were not used as research methods in any of the primary studies.

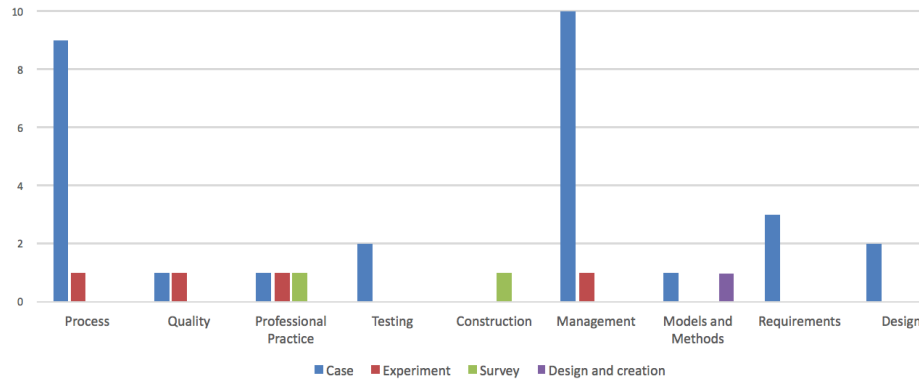


Figure 4: Empirical Evidence, 2013-2017

470 Figure 5 illustrates contribution types (as applied in Paternoster et al. [7], originally suggested by Shaw [58]) within each each knowledge area between 2013-2017. The 9 different knowledge areas are represented a total of 49 times through 7 different contribution types. These include (1) model, (2) theory, (3) framework, (4) guidelines, (5) lessons learned, (6) advice, and (7) tools (table A.9). Lessons learned is the most frequently used contribution type (43 percent), followed by advice (25 percent), model (12 percent), theory (10 percent), framework (5 percent), guidelines (5 percent), and tools (3 percent).

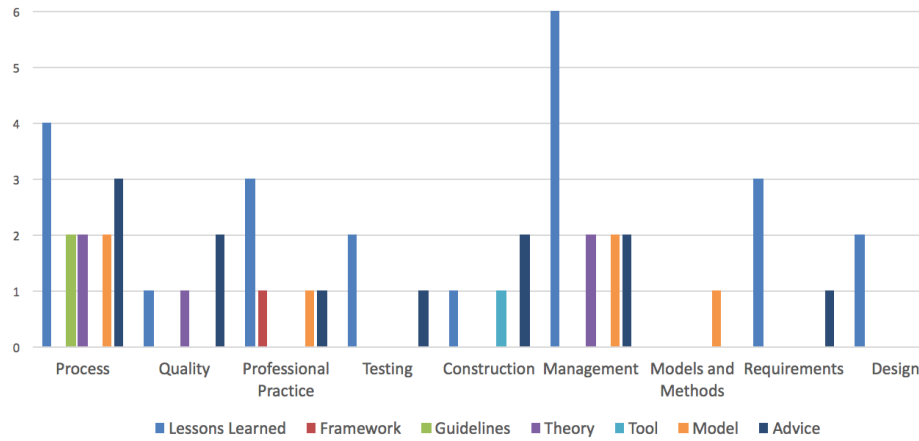


Figure 5: Contribution Types, 2013-2017

475 Figure 6 presents the number of papers that cover the different knowledge areas in our study (red columns) and Klotins et al. [8] (blue columns). The total number of primary papers in Klotins et al. [8] was 14. Both mapping studies include papers that cover more than one knowledge area.

480 The newly selected primary papers from 2013-2017 cover 9 of 15 knowledge areas. The ones missing are (1) software configuration management, (2) software engineering economics, (3) software maintenance, (4) computing foundations, (5) mathematical foundations, and (6) engineering foundations.

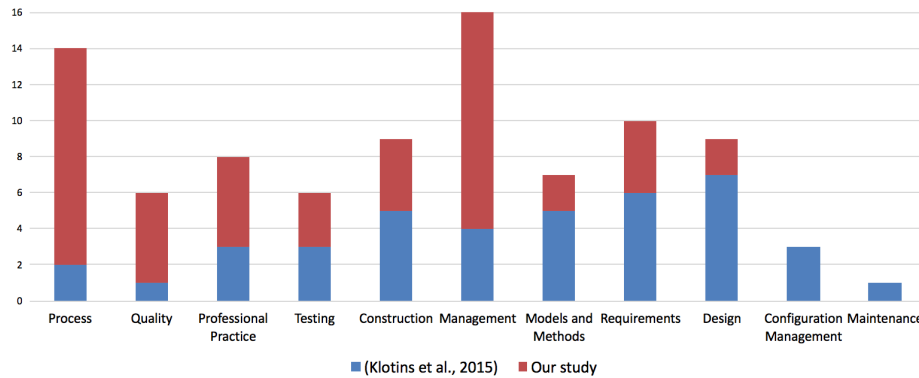


Figure 6: Knowledge Area Coverage, 1994-2017

485 From figure 6, we see that there is a significant change in the research direction for the last five years. Between 1994-2013 “software design” and “software requirements” are the most represented knowledge areas, whereas “software

engineering process” and “software management” have received significant attention from the community between 2013-2017. “Software configuration management” and “software maintenance” are only covered between 1994-2013.

490 Paternoster et al. [7] did not present any results in relation to the SWE-BOK knowledge areas. However, they provided the contribution type of each primary study. Figure 7 shows the contribution types of primary papers between 1994-2017, separating the periods before and after 2013. The most frequently provided contribution types between 1994-2013 were advice and model, while lessons learned was most represented between 2013-2017. The least frequently used ones combined from both studies were framework, guidelines, and tools.
495

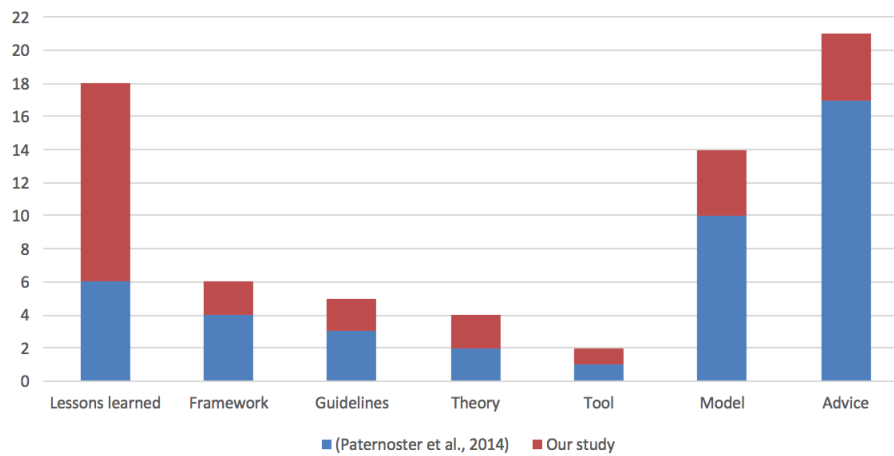


Figure 7: Contribution Types 1994-2017

4.2. RQ2: What is the relative strength of the empirical evidence reported?

To address this research question, we have made a bubble chart of each knowledge area with the corresponding rigour-rating. Among the 27 new primary papers, only the papers that provided empirical evidence were evaluated
500 (22 of 27). The quality assessment will be compared to both of the previous mapping studies.

4.2.1. Rigour of Primary Studies 2013-2017

Publication venue can be interpreted as an initial indicator as to whether the papers provide scientific quality. Among the newly selected primary studies, 21
505 were conference papers, 5 were journal papers, and 1 paper was a book chapter. However, it is necessary to perform a more comprehensive quality assessment process in order to compare results across different studies.

Figure 8 shows the degree of rigour within each knowledge area between 2013-2017. The figure is based on the quality assessment (table B.10). The
510 x-axis represents the knowledge areas, while the y-axis represents the rigour.

Only one paper received low rigour score [59], as it didn't provide enough details about the data analysis and included no assessment of the validity of the results. However, as only the papers providing empirical evidence were assessed, it is possible that more papers would receive low rigour as well. In general, the papers received high rigour score, indicating that the quality of research was high.

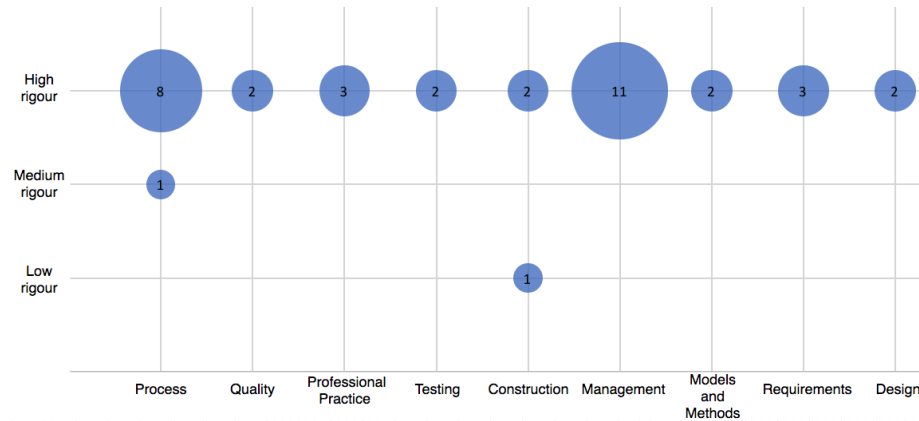


Figure 8: Rigour of each covered knowledge area, 2013-2017

4.2.2. Rigour of Primary Studies 1994-2013

Figure 9 shows the rigour of the primary studies from Klotins et al. [8], and which research type each constituted. The paper did not specify how they calculated the rigour of each paper. The x-axis represents the research types, and the y-axis represents the rigour. From 14 primary papers, only one provided a contribution of high rigour. Most of the papers (86 percent) obtained low rigour. As to this, the paper concludes that the low rigour of the papers, due to poor contextual descriptions, makes it hard to transfer results from one environment to another.

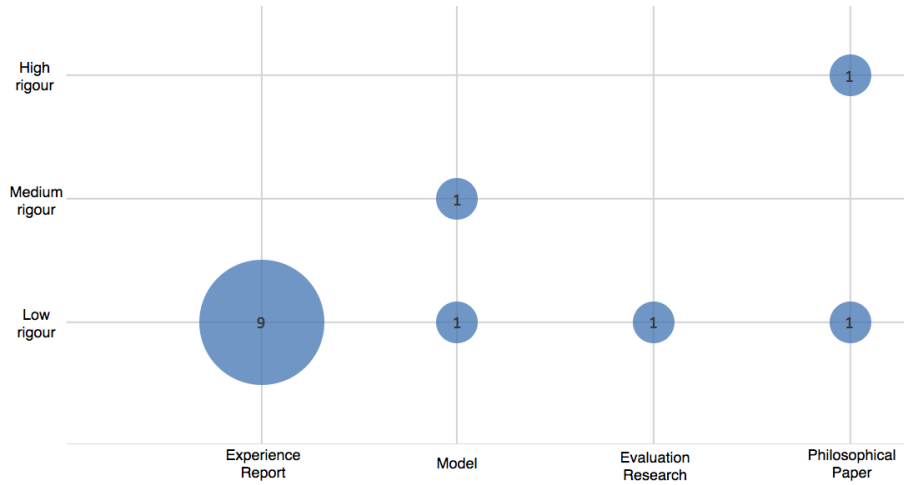


Figure 9: Rigour and Research Type [8]

Figure 10 illustrates the rigour of the contribution types provided by each of the primary papers in Paternoster et al. [7]. The x-axis represents the contribution types, and the y-axis represents the rigour. The division of rigour score is based on table 7 in the study. Papers that got a total score above 7 received high rigour, between 4 and 7 received medium rigour, while less than 4 received low rigour. 70 percent of the papers in figure 10 received a medium score, while 21 got a high score.

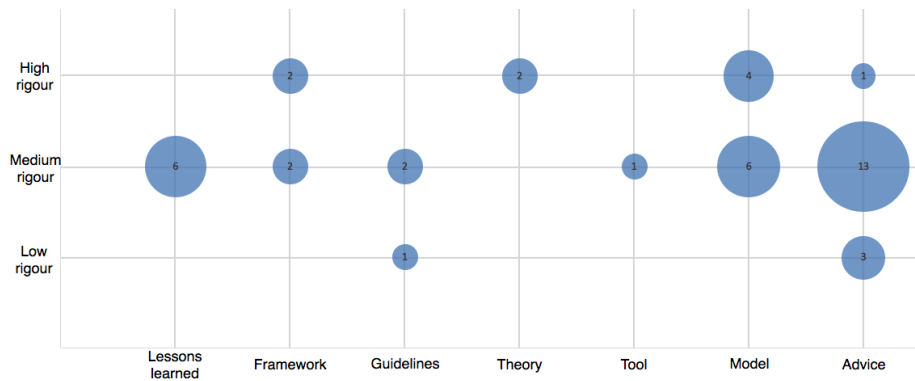


Figure 10: Rigour and Contribution Type [7]

Comparing the tables it becomes evident that the rigour of primary papers has increased from the period 1994-2013 to 2013-2017. Recently software process and management have received a significant amount of high-quality re-

search. The other knowledge areas have received little attention, however of high-quality. The quality assessments are subject to bias from several reasons: (1) different quality assessment criteria, (2) different rating systems, (3) different researchers providing various experience and knowledge to the assessment process, (4) contributions from multiple authors from different time periods. To mitigate systematic errors, we defined clear inclusion criteria, and author one and two collaboratively assessed the newly selected primary papers.

4.3. RQ3: In what context has software startup research been conducted?

This section is divided into three sub-sections identifying the contextual descriptions provided in the period 1994-2017. Section 4.3.1 shows how papers characterize the startup context, and how they use the term for “startup company” differently. Section 4.3.2 shows whether the papers from 2013-2017 focus on startups in the context of incubators. Section 4.3.3 presents in detail the contextual descriptions provided by papers between 2013-2017.

4.3.1. Thematic Concepts and Term Frequency

To illustrate how researchers use different definitions and thematic concepts in their characterizations of startups, we extracted the thematic concepts (i.e., referred to as recurring themes in Paternoster et al. [7]) between 1994-2017. Paternoster et al. [7] extracted 15 themes from 43 papers (explained in table B.11). As to this, it is possible that other selections of papers would have provided a different set. The thematic concepts constitute a solid base for characterizing startups, presenting what are the most common perceived characteristics when talking about startups among research. A coherent use of thematic concepts to characterize software engineering can help researchers and practitioners judge whether research results can be generalized and transferred to other startup engineering contexts. To extract the frequency between 2013-2017, the first and second author read the full text of the primary papers. In addition, searches were performed in the pdf-version of each paper to find the frequency of thematic concepts.

Table 3 presents a complete usage of thematic concepts operating startup research between 1994-2017. We observe that the characterizations have changed over time (e.g., the most frequently used concept before 2013 was only the fourth most used one after 2013). The differences are significant since it is only four years between the studies. The use of concepts between 2013-2017 is highly inconsistent. There is no single concept that all the 22 empirical papers use for the startups they investigate. The low frequencies of the thematic concepts also illustrate that many of the papers provide poor startup descriptions.

Thematic Concepts	Frequency 13'-17' (#27)	Frequency 94'-13' (#47)
Innovation/Innovative	15	19
Uncertainty	14	15
Small team	11	12
Lack of resources	9	21
Little working/operating history	9	3
Time-pressure	7	17
Rapidly evolving	5	16
New company	5	8
Highly reactive	3	19
Highly risky	3	8
Third party dependency	2	12
One product	2	9
Not self-sustained	1	3
Low-experienced team	0	9
Flat organisation	0	5

Table 3: Thematic Concepts, 1994-2017

Table 4 shows the number of primary papers from 1994-2017 using the specified terms for “startup company”. In situations where the title did not use any of the terms, the abstract was revised. Several papers [60, 61, 62, 63, 64] did not use any of the terms or was not found. From the table, it can be observed that the use of terms for startup companies has changed. The most significant finding is that the term “startup” is more frequently used now than before. 75 percent of the studies from 2013-2017 used the term “startup”, compared to 48 percent in 1994-2013. 15 percent used the term “start-up” in the period 2013-2017, while 48 percent used the term “start-up” between 1994-2013. The inconsistent use of terms is one of the main challenges for developing a coherent body of knowledge within software startup engineering. Even though 40 studies used the term “startup”, the context for which they were used was not the same, or the study context was poorly described.

Term	Frequency 13'-17' (#27)	Frequency 94'-13' (#42)
Startup	20	20
Start-up	4	20
Very small entity	1	0
Very small company	1	1
Very small enterprise	1	1

Table 4: Term Frequencies, 1994-2017

4.3.2. Incubated Companies

Figure 11 shows the percentage of the newly selected empirical papers that have performed research in the context of incubators. That is, mentioning incubators or presenting research on startups that are part of incubator environments. As illustrated, 91 percent of the papers focused on startups outside

of incubator context or did not mention this in their description. Two papers focused on incubated startups [65, 66].

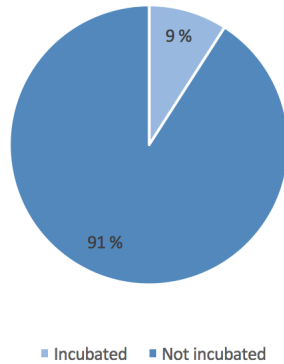


Figure 11: Percentage of Incubated Companies, 2013-2017

4.3.3. Contextual Descriptions

The primary studies from 2013-2017 that have provided empirical evidence and sufficient contextual descriptions are presented in table 5. The relevant context information includes the attributes: (1) number of startups under investigation, (2) size of the company/team, (3) the product orientation of the startups, and (4) other relevant contextual descriptions beyond these three (e.g., lifecycle stage, age/year of establishment, location, software development methodology).

As illustrated in the figure, 14 of the 22 studies showed a sufficient amount of contextual description. The contextual descriptions in the remaining eight papers were either absent or not sufficiently explained. The papers not providing empirical evidence were not evaluated. The two last papers in the table are subject to omission, as both have two fields of "not specified".

The following list presents some of the descriptions of companies that have participated in empirical research on startups, and explanation of non-trivial information.

- The number of startups under investigation is in the range from 1-20 startups. The most frequently used number of startups was found to be 3-5.
- The number of employees is usually in the range of 2-25, depending on the lifecycle stage of the company. At early stages, the number of employees tends to be equal to the number of founders, which seems to be in the range of 2-6. At later stages, more employees are needed. For the scaling phase, most companies have 10-20 employees.
- It is usual that researchers specify the product orientation of the startups (e.g., B2B/B2C).

- 620 • The age of the investigated companies is usually in the range 1 month to 3 years. Some papers investigated VSEs, one of them 18 years active [67]. Companies beyond three years of age tend to be past the scaling phase.
- Startups use different software development methods. The most usual methods found were agile, scrum, or ad-hoc.
- No more than two papers mentioned whether the investigated companies had received any funding, and if so what kind of funding they had received.
- 625 • Even if some of the investigated startups develop products with mixed software and hardware parts, no paper focused on their specific challenges or practices.
- A bootstrap startup is a company that started out without initial funding and resources [46].
- 630 • “VSEs” and “high growth firms” can in the related studies be regarded as startup companies.
- In relation to the startup stages presented in section 2.3 (1) Concept and pre startup stage are similar to stage 1. (2) Implementation, functional, and startup stages are similar to stage 2. Commercial and scaling stages are similar to stage 3. (4) Mature stage can be either stage 3 or 4.
- 635

ID	Nr of startups	Company size	Product orientation	Other relevant info
[30]	1 startup	5 members	Social network application	Roles: Designer, 1 web/iOS/android dev. each, CEO Approach: Lean Startup/Agile
[14]	3 startups	4 members 6 members 25 members	Health E-commerce E-commerce	Canada, mobile app, concept stage Italy, mobile and web app, func.stage Brazil, web app, mature stage
[66]	4 startups	12 members 10 members 8 members 10 members	Academic business domain	3yrs old 1yrs old 1yrs old (still incubated) 4months old (still incubated)
[68]	1 startup	Not specified	Db performance & interoperability	High potential growth firm, spin-out from a university
[44]	4 startups	2 founders 3 founders 2 founders 2 founders	Video service SaaS Event ticketing system Game-based learning	Working prototype (14') Func. product, limited users (15') Func. product, high growth (11') Mature product (06')
[28]	5 startups	6 members 4 members 18 members 3 members	Online photo marketplace Marketplace for food hub Collab.platform construction Sale visualization Under-water camera	Italy (lean startup/agile,12',impl.phase) Norway (ad-hoc,15',concept.phase) Norway (Scrum,11',commercial.phase) Norway (agile,11',commercial.phase) Finland (ad-hoc,11',impl.phase)
[45]	5 startups	20 members 18 members 1 member 3 members 1 member	Learning game, B2C Real-time sale management, B2B Photo marketplace, B2C Social platform,B2C Collab.platform construction, B2B	2006, scaling phase 2011, scaling phase 2012, startup 2015, pre-startup 2011, startup
[46]	6 startups	6 members 9 members 3 members 5 members 12 members 5 members	Hyper-local news platform, P2P Collab.platform construction, B2B Ticket event system, B2B Shipping platform, P2P Game learning tool, P2P Fish farm management, B2B	Norway (agile,2015,bootstrap) Norway (scrum,2012,bootstrap) Norway (agile,2012,bootstrap) UK (agile,2013,early investor) UK (dist.agile,2013,bootstrap) Vietnam (ad-hoc,2016,bootstrap)
[69]	2 startups	4 members 2 members	Not specified	Peru (2012, VSE/start-up term) Canada
[56]	3 startups	4 members 5 members 12 members	Photo market place, P2P Under-water camera, B2B Ticketing system, B2P	2011,paying customers 2009,paying customers 2011,paying customers
[67]	3 VSEs	17 members 10 members 7 members	Enterprise Financial services Enterprise	18yrs active (int.customers) 9yrs active (int.customers) 4.5yrs active (int.customers)
[5]	13 startups	3-20 members 2-6 founders	Not specified	Time-to-market: 1-12months
[65]	8 startups	Not specified	Not specified	Incubator-context 62 % used pseudo-agile for reqs. 100 % not documenting many reqs.
[13]	3 startups	Not specified	Food-waste knowledge app Online debt platform Online investment platform	Not specified

Table 5: Contextual Descriptions, 2013-2017

Table 6 presents a summary of the main findings contributing to addressing our research questions: (RQ1) *How has software startup research changed over time in terms of focused knowledge areas?* (RQ2) *What is the relative strength of the empirical evidence reported?* (RQ3) *In what context has software startup research been conducted?*

Research Question	Findings
RQ1	Most research has been conducted within the knowledge areas software process, management, construction, design, and requirements, with the shift of focus toward process and management areas. Researchers have provided lessons learned and advice studies, paying less attention to specific tools and frameworks.
RQ2	The rigour of primary papers was higher between 2013-2017 than that of 1994-2013. Two reasons for this are increased importance of startups, and increased focus on researchers providing high-quality research.
RQ3	Thematic concepts representing the software startup context include innovation, lack of resources, uncertainty, time-pressure, small team, highly reactive, and rapidly evolving. Startup literature provides an inconsistent use of thematic concepts describing startups.

Table 6: Summary of results

5. Discussion

In this paper, we have applied a systematic mapping method to analyze the 74 primary papers, to observe how software startup research has evolved and possibly matured in some Software Engineering knowledge areas. This makes it possible to identify changes in research direction for the last five years. This section presents our discussion of the newly selected papers along with the SWEBOK knowledge areas, identifying state-of-the-practice and pointing out existing research gaps. From the extracted context features, we provide a synthesized description of the startup context.

5.1. RQ1: How has software startup research changed over time in terms of focused knowledge areas?

5.1.1. SWEBOK Knowledge Areas

Software Engineering Process. The need for the software development process to be adapted to a project’s scope, magnitude, complexity, and changing requirements is generally acknowledged, however, there exists a lack in guidance on how software startups can adapt their process to their situational context [68]. The situational context consists of a large number of concerns and factors, as found in the “reference framework” [70], indicating why software engineering is so hard [68]. The situational factors in the reference framework explain the need for startups’ own software development processes, and why strictly following the agile methodology is often outside the scope of small startups [30]. In early-stage software startups, research shows that systematic software engineering processes often are replaced by light-weight ad-hoc processes [11].

Software startups need a model fitted to both the innovation, and engineering processes in startups’ complex and chaotic situations. The Hunter-gatherer cycle is one model proposed to help startups in all phases of the company,

from their evolution from innovative ideas to commercial products. The model differentiates between the hunting cycle, and the gathering cycle, which covers the innovation and engineering activities. The model is at a preliminary stage and requires more empirical evidence in order to be generalized to all software startups [56].

Software Engineering Professional Practice. Software engineers need to possess the required knowledge, skills, training, and experience to practice professional and responsible software engineering [9]. Standards like ISO are meant to ensure high quality and reliability of software products [71], and can thus help developers to practice software engineering at a level in line with these objectives. The paper by Laporte and O'Connor [51] presents results from early trials of the ISO/IEC 29110 standard for very small entities and concludes that international certifications can enhance small software companies' chances for success.

Developers in software startups typically prioritize speed related agile practices rather than quality related ones [72]. Standards like ISO, tailored to the startup context, can help software developers combine quality and speed, which in turn can increase the chances for success. However, as the ISO/IEC 29110 standard mainly is intended for very small companies, it is only partially relevant for startups. Future work should be undertaken to develop an ISO standard tailored to the startup context, to support developers in practicing professional software engineering. In general, there was a lack of research supporting professional practice in software startups.

Engineering foundations is one of the 15 knowledge areas that was not covered in any paper. It is about the application of knowledge in the engineering discipline, allowing engineers to develop and to maintain software more efficiently and effectively, and help practitioners to adopt professional software engineering principles. As to this, more work should be undertaken to identify the engineering foundations of software developers in startups. Most prior research has focused on the needs of established companies. A possible research area could be to investigate which engineering practices graduates and other engineers should possess if they are to work in a software startup, and how universities and other educational institutions can facilitate learning and other services to support the specific needs of practitioners that are to work in software startups.

Software Engineering Management. Software engineering management concerns about a wide range of different areas, including planning, measuring, coordinating, and reporting activities to support systematic software development and maintenance [9]. For startups, software engineering management relates to, among other things, business model experimentation and customer development.

Three primary studies that have identified software engineering management are [73, 56, 74]. However, these papers primarily focus on software engineering processes [73, 56] and software quality [74]. Although the Hunter-gatherer cycle presented by Nguyen-Duc et al. [56] presents how startups can handle the

dynamic evolution of product-market fit, which is part of both business experimentation and customer development, it is primarily focused towards software engineering processes in startups.

715 The managerial part of software engineering has been identified by Nguyen-Duc and Abrahamsson [46], exploring the outsourcing relationship in software startups. They concluded that outsourcing is a feasible option for early-stage startups. The authors are underway to provide a guideline with best practices for outsourcing in startups.

720 Other papers have focused on principles from Lean Startup, especially the role of pivoting in software startups. This includes why startups pivot [29], and which pivot types exist [44]. More work is required to address the consequences and relationship among different pivot types, both from a business and technical perspective. How pivoting should be performed at different lifecycle stages, both in terms of system complexity and modifiability, may affect the pivoting
725 decision.

The research agenda [1] has addressed a need for more research to identify how startups explicitly manage risks, and how startups can model and measure risks. This further relates to which tools and techniques they should utilize to preserve agility and speed in dynamic environments of high uncertainty. Lean
730 Startup offers entrepreneurs a method to handle such environments, but more empirical evidence is needed to understand how software startups apply this theory in practice so that researchers can develop tailored models and frameworks to reduce business and technical risks.

Software Quality. A frequent issue in terms of software quality for startups is
735 technical debt. The development of minimum viable products, and releasing the product as fast as possible, often require the development team to take shortcuts and workarounds. Steve McConnell showed that technical debt can be divided into intentional and unintentional debt [75]. Shortcuts can lead to the accumulation of intentional technical debt, while unintentional technical
740 debt can happen when business model experimentation is leaved out [74]. No matter how good the idea may seem, not validating the idea with customers could lead to the development of unnecessary features.

Not focusing on technical debt will have consequences for the product quality, while constantly changing and improving the business model will be necessary
745 to stay competitive [74]. Finding the correct balance is therefore essential. The same problem is referred to as the developer's dilemma [76]. The developer's dilemma also emphasizes the need for managers to communicate the learning goals of the product precisely so that developers can adjust the quality accordingly. Not finding the correct match between learning goals and quality will
750 often lead to technical debt, waste, or missed learning.

To help startups focus on technical debt, one estimation method is proposed based on Visual Thinking [77]. The technique is based on "duck taping" each part of the code that is developed or fixed in a messy way, to keep an overview of what might cause quality issues in the future. Measuring technical debt is hard,
755 and as the author also concludes, the method needs more empirical evidence as

to whether it actually is capable of solving issues related to technical debt.

Software Construction. There exists a wide range of various software tools to speed up the development processes in software startups. However, as Edison et al. [59] suggest, there does not exist a clear understanding of how entrepreneurs can use the different tools efficiently to meet their specific needs. As to this, the paper describes the outline of a system that provides a software tool portal that supports and recommends which tools to use in the construction of software products and services. The portal can be directly connected to the research agenda [1], which addresses a need for how software tools can be recommended and used by entrepreneurs.

According to our findings, there is a general lack of research within the field of software construction in startups. A software tool portal can indeed be helpful to support software construction. However, such a portal is not specifically addressing how to construct software. Software construction includes the management and practicalities of construction and the use of technologies and tools to develop software [9]. As to this, it can be feasible to address software construction through sub-categories, like design, testing, and verification.

Software Engineering Methods and Models. The models and methods knowledge area aims at making software processes more success-oriented through systematic and repeatable activities at different lifecycle stages [9]. Topics include principles and properties of models, analysis of models, and various software development methods.

Startups need software development methodologies and techniques tailored to their specific contexts. These should be based on Lean Startup and agile principles [7]. Researchers are encouraged to identify what engineering methods and models that are used today, and whether they work in a startup context [1].

The Greenfield Startup Model (GSM) aims at explaining how development strategies and practices are engineered and utilized in startups [5]. A similar model, the academic startup model, was created by Souza et al. [66], which illustrates how software startups structure and execute their engineering activities. Both papers conclude that early-stage software startups do not adopt traditional development methodologies. Instead, rapid prototyping and continuous experimentation are in focus, hence engineering practices are adapted to each startup's specific context. These models provide development objectives that software engineers in startups can use, as well as guidelines for future research aiming at improving the current state-of-the-art.

We see an existing need to validate the software engineering models adapted to the startup context. This includes areas like technical debt management for particular contexts, and how new models from academia and industry can be applied in the startup context [5].

Software Testing. Software validation and testing are essential parts of all software engineering processes. Software testing is both costly and time-consuming,

and without sufficient knowledge about customers and users, it can be difficult
800 for startups to apply necessary testing practices in the development of high-
quality software products and services.

Pompermaier et al. [65] found that testing is critical to startups' success.
However, in the construction phase of the first version of the system, technical
teams did not use any software testing techniques. This changed in the following
805 phases, where 75 percent of the technical teams used software testing techniques.
The most common testing techniques were unit tests (37 percent), pilot clients
(25 percent), functional tests (25 percent), and specialist testers (13 percent).

Due to the importance of testing, startups should apply testing techniques at
a more consistent and detailed level to enhance the quality and professionalism
810 of their development processes. Apart from the results presented by Pomper-
maier et al. [65], more research is required to identify and develop methods for
how startups can enhance their current testing processes, even in contexts of
scarce resources and time-pressure. Research should look at how startups can
learn from established companies' systematic testing processes, even if they have
815 significantly different needs for, and usage of such methods. Finding an opti-
mal balance between cost/time spent on testing activities and how this evolves
over time in startups can help them in the introduction of good software testing
practices [1].

Software Requirements. Software requirements engineering activities include
820 elicitation, negotiation, analysis, specification, and validation of requirements
[9]. As startups lack knowledge about their customers and users, it becomes
difficult to identify and also verify all requirements. How much time should be
spent on requirements is challenging to estimate when you don't know whether
the requirements actually will be implemented. This, in turn, makes it difficult
825 to estimate time and cost of software development. To deal with these ambigu-
ities, startups should apply techniques from the Lean Startup methodology [12].
Prototyping, continuous experimentation of minimum viable products, and piv-
oting are effective tools and methods startups can utilize in their requirements
engineering processes [1].

Rafiq et al. [14] found that there was a lack of studies investigating how
830 software startups perform requirements engineering processes. The study found
that requirements mainly were elicited through the founders' assumptions and
interpretations of the market. These were based on several different require-
ments elicitation techniques, including prototyping, interviews, questionnaires,
835 feedback comments analyses, competitor analyses, similar product analyses, col-
laborative team discussions, and model users. Although elicitation techniques
were used, the startups did not define the requirements explicitly. This resulted
in a lack of formal documentation, both before and after the elicitation process.

Future research should investigate a larger number of software startups to
840 identify a greater amount of elicitation techniques and to provide stronger evi-
dence of the findings in Rafiq et al. [14]. More research should be undertaken
to identify negotiation, specification, and validation techniques. In addition,
research is necessary to identify requirements engineering for different lifecy-

cle stages to help startups in specific situational contexts identify appropriate
845 requirements engineering techniques.

Software Design. The role of MVPs in software startups has been addressed
by Nguyen-Duc and Abrahamsson [28]. They suggest that MVPs are effective
tools for requirements elicitation, and for bridging knowledge gaps between en-
trepreneurs, investors, and software developers - emphasizing that MVPs can
850 serve as a multiple facet product. A research topic requiring more work is how
software prototype practices can be applied in an agile development context, and
how startups can benefit from adopting open source software in prototyping.

The speed of prototyping has been addressed by Nguyen-Duc et al. [17]. The
factors that influence the speed of prototyping can be grouped into artifacts,
855 team competence, collaboration, customer, and process dimensions. These fac-
tors, along with the uncertainties of the startup context make it important to
define practices and processes to support decision-making in prototyping. While
throw-away prototypes are used mainly for specification and experiments, evo-
lutionary prototypes provide a basis for complete systems, usually developed
860 with extensive reuse. Customer feedback is an essential part of business ex-
perimentation and is mainly done through prototyping. More work is required
to identify what kinds of learning different prototypes provide and to identify
effective prototyping and development patterns among software startups.

5.1.2. Startup Research 1994-2017

865 Matching the primary papers with the right knowledge area can be challeng-
ing, one reason being their relevance to the startup context. Another issue is
that different perceptions of knowledge areas can give different classifications.
Different authors' biases in terms of knowledge and personal opinions will also
lead to different classifications.

870 Looking at the knowledge areas covered between 1994-2017, we see that soft-
ware maintenance and software configuration management have received few
contributions. As one of the most important objectives for startups is to grow
and scale their business, both maintenance and configuration management be-
comes more important at more mature lifecycle stages. No papers between
875 2013-2017 focused on these knowledge areas, illustrating their irrelevance to the
startup context.

Four knowledge areas were not covered at all (computing, mathematical, and
engineering foundations, and software engineering economics). They character-
ize the educational requirements of software engineering, hence not particularly
880 relevant for specific software startup research. However, we argue that more
research should be provided within engineering foundations, as it can serve as
a prerequisite for software practitioners in startups. Apart from these findings,
we observe that the areas models and methods, testing, and quality have re-
ceived few contributions. In contrast to the educational requirements, these are
885 of greater importance in all startup lifecycle stages, and should thus be given
more attention in future work.

Areas with numerous contributions include software engineering process, software engineering management, software construction, software design, and software requirements. Management was suggested by Klotins et al. [8] as a potential area for future work. Recently, several papers have contributed to important managerial aspects like pivoting, experimentation, and the role of prototypes to define and assess business and development scope. It is clear that the startup context requires fast and effective decision-making, both at a managerial and technical level. Software requirements engineering is important to manage in order to minimize time and costs and avoid feature creeps related to prototyping and business experimentation.

Another area not sufficiently covered between 1994-2013 was software engineering process. This is in contrast to the last five years, where process has received most contributions. Klotins et al. [8] argue that software engineering process becomes relevant for the maturity phase when product development is more robust and processes more predictable. As to this, the software process knowledge area is more relevant for SMEs. In our study, however, we have regarded process as relevant for early-stage development as well, illustrating the different interpretation among researchers.

The publication frequency of primary papers between 1994-2017 indicates that increasingly more papers are published. No other year is more represented than 2017, which indicates that there is an increased focus on research within the field. This can be seen as a direct response to the research agenda's [1] identified need for more research and the increased impact and importance of startups in today's technology innovation processes. The highly dynamic markets and ever-increasing customer demands lead to a high failure rate among startup companies. Empirical studies have found that although startups try to adopt Lean Startup principles and agile methods, they generally find it hard to apply them [5, 66]. More research is thus required to support entrepreneurs and software developers to enhance their chances of success. With the increased publication frequencies in mind, it seems that more work is undertaken to address startups' unique needs.

Software startups find it hard to apply theory in practice, a claim supported by both empirical research and the high failure rates. Looking at the contribution types from 1994-2017, we observe that the most frequent ones are advice, lessons learned, and models, while the least frequent ones are tools, guidelines, and frameworks. Between 2013-2017, lessons learned has been the most popular contribution type, while previously advice was more popular. What we can make from these numbers is that researchers mainly have focused on providing advice and learnings to the startup community. As to this, we suggest that researchers should provide knowledge from state-of-the-practice to support startups with specific tools and frameworks. This could allow for a broader coverage of startups' needs and unique requirements.

5.1.3. Identification of Research Gaps

By structuring literature within the field from 1994-2017, this study allows for identifying whether research from the last five years has addressed research

gaps suggested by the previous mapping studies. In addition, this section will point out directions for future research.

Paternoster et al. [7] expected more studies to contribute to the adoption of agile practices in startups. In particular, they recommended the need for future studies to provide techniques for aligning business goals of software startups with the execution of specific development practices. Another area suggested for future research was the development of customer collaboration processes for requirement elicitation, allowing for testing the problem before releasing the product to market. Lastly, they identified the need for improved verbal communication with the introduction of new tools and techniques to enhance knowledge transfer in startups. These research gaps have only partly been addressed the last five years. Towards agile methodologies and techniques tailored to the startup context Pantiuchina et al. [72] provide a better understanding of the current adoption of agile practices in software startups. The study indicates that speed-related agile practices are more frequently used than quality-related practices. Comparable findings have been presented by Yau and Murphy [30], stating that a rigorous agile methodology intended for established companies may not be applicable to the startup environment. In relation to customer development Chanin et al. [13] present the results from applying a customer development process to three startups, indicating that the process can improve the requirements process. Others have also contributed to addressing customer development and requirements elicitation [14, 28, 44]. We could not identify research directly related to team communication, documentation, or knowledge transfer.

Klotins et al. [8] stated that there is an insufficient understanding of quality requirements role in software startups, and that maintenance of product integrity in startups is yet to be explored. This is especially relevant due to the evolutionary approach and restricted resources of startups. Similar to Paternoster et al. [7], Klotins et al. [8] highlight the need for addressing the relation between software technical decisions and organizational business goals, and a better understanding for human capabilities in startups. Comparable to the need for customer development processes presented by Paternoster et al. [7], Klotins et al. [8] identified the need to further investigate the role of scope in software startups. Discovering the right scope can greatly improve development speed, by identifying the necessary features and effort. Since 2013 empirical research has been undertaken to explore state-of-the-practice in testing activities of software startups [65], and the accumulation of technical debt [74, 76, 77].

We suggest future work to compile a set of agile practices that provide enough benefits to be adopted in the startup context, overcoming challenges related to cost and time of implementing a process model without compensating the demand for speed in early-stage startups. A development methodology should include specific practices related to communication in the growing number of stakeholders. We also emphasize future studies dedicated to the role of human capital in startups, investigating capabilities and engineering foundations of startup practitioners. In addition, we highlight the need for studies exploring challenges and engineering approaches of startups developing products with

mixed hardware and software parts. Finally, more work is needed to cover the partly filled research gaps identified by the previous mapping studies.

980 *5.1.4. Future Classification*

Unterkaustein et al. [1] identified more than 70 research questions in different areas supporting activities of software startups. The researchers contributing to the paper are all part of a network (The Software Startup Research Network) of researchers that have created eighteen research track descriptions
985 to ease the presentation and discussion of the research agenda. These eighteen research tracks were grouped into six themes based on similarities.

Classifying the newly selected primary studies according to the SWEBOK knowledge areas resulted in 9 out of 15 of the areas being addressed. This indicates that some of the knowledge areas might not be related to startups, while some are of big interest. The same pattern was discovered in Klotins et al.
990 [8], which used SWEBOK for lack of a better alternative. The low coverage is most certainly because most of the research in the field of software engineering is undertaken in relation to established companies, from which the SWEBOK knowledge areas are developed.

For future mappings, it would be sensible to categorize the papers into the newly established research themes [1]. These are better suited for startup research and can help guide researchers in providing knowledge to the specific areas that are most important for the challenges faced by startups. Do notice that number 7 and 8 require more evidence as to whether they can be related to
1000 software startup engineering: (1) Supporting startup engineering activities, (2) Startup evolution models and patterns, (3) Human aspects in software startups, (4) Applying startup concepts in non-startup environments, (5) Startup ecosystem and innovation hubs, (6) Methodologies and theories for startup research, (7) Marketing, (8) Economics and business development.

1005 *5.2. RQ2: What is the relative strength of the empirical evidence reported?*

Paternoster et al. [7] provided a mapping of the research within software development in startups for the period 1994-2013, including 43 primary studies. Each study provided empirical evidence as this was a quality criterion of the mapping. Overall, only 4 of these papers were found to be (1) contributions
1010 entirely dedicated to engineering activities in startups, (2) providing a strong contribution type, and (3) conducted through an evidence-based research approach [10, 37, 38, 39].

The mapping study Klotins et al. [8] found that (1) most of their primary studies did not compare and analyze data from more than one case, and (2) most
1015 studies had low rigour, making it difficult to compare results. As to this, they emphasized the need for more empirical research to provide stronger evidence and enable results to be generalized to all software startups. More specifically, the paper identified a lack of studies related to requirements processes, the “developer’s dilemma” (as discussed in section 5.1.1), software architecture, and
1020 software engineering processes.

Figure 4 shows the areas that have received most contributions in terms of empirical research between 2013-2017. These are software engineering process, software engineering management, and software engineering professional practice. On the contrary, five knowledge areas received less than five scientific contributions, arguing the need for more research, even within areas that have gotten attention from the research community. This is also in line with the research agenda's addressed need for further empirical evidence [1].

Comparing the provided quality between papers published before and after 2013 we see that the quality of work is improving. As for the previous studies, the reported rigour of the primary papers was at a generally lower level than what was found in the newly selected papers, where only one paper obtained low rigour. Possible explanations are the different quality assessment methods used, and the increasing number of researchers contributing to the field. Another reason may be the assessment bias of different researchers.

Several of the researchers who have contributed to the newly selected primary papers are members of The Software Startup Research Network, whose aim is to provide entrepreneurs and the research community with novel research findings within the area of software startups. Anh Nguyen-Duc, one of the members of this network, has participated in six of the primary studies, in which all received a high rigour score. Another researcher who has contributed to three of the primary studies is Rory V. Connor, where all three papers received a high rigour score. He participated in three primary studies in the previous systematic mapping study as well, all of which obtained high rigour. As to this, it seems that the quality of research is becoming increasingly high compared to before, justifying the high rigour obtained by the quality assessment in this mapping study. The quality of work was reported to be a problem area in both of the previous mapping studies. However, as our findings suggest, there is an increased focus on providing high-quality research with several researchers contributing with multiple papers, as illustrated by specific initiatives that promote scientific work.

5.3. RQ3: In what context has software startup research been conducted?

The most frequently used term for referring to startup companies is "startup", with 54 percent of the 74 primary papers using this term. Between 2013-2017, the same percentage has increased to 75 percent. In order to create a coherent definition for startups, ideally, only one term should be used. The research community has moved towards a common use of "startup", and this should thus be used for future research when referring to companies in the startup context. Inconsistent usage of the term, like "start-up", "start up", or "very small entities" in startup context should be avoided, and makes it difficult for both practitioners and researchers to adopt relevant results.

Primary papers showed an inconsistent use of thematic concepts when describing startup companies, with no single factor being used by all papers. As stated in the results, this also relates to the poor contextual descriptions found in several of the papers. We observe that the usage has changed significantly between 1994-2017, where only "Time-pressure" was used to the same extent

before and after 2013. Interestingly, the least used concept between 1994-2013 is the fifth most used concept by the papers between 2013-2017. As to this, it seems that some of the thematic concepts found in the previous mapping study are no longer the ones used by the community.

1070 The many different descriptions of startups make it challenging to develop a coherent definition and body of knowledge for the startup context. Based on the frequency of concepts found in the primary papers between 1994-2017, we argue that at least the concepts occurring in more than 25 percent or more of the studies should be part of a unique definition of startups. The following
1075 thematic concepts were: (1) Innovation/innovative, (2) Lack of resources, (3) Uncertainty, (4) Time-pressure, (5) Small team, (6) Highly reactive, (7) Rapidly evolving. Thematic concepts that were not very relevant for startups include not (1) self-sustained, (2) low-experienced team, (3) one product, and (4) flat organization. These concepts should be avoided as the primary definition by
1080 researchers in the community.

Many of the newly selected primary studies did not explain the startups under investigation sufficiently. From the 22 papers providing empirical evidence, only 14 of these provided a sufficient amount of descriptions (table 5). Interestingly, only two papers mentioned incubators as part of the startup context.
1085 Without a unique definition in literature, the importance of precise descriptions becomes even bigger, especially for transferring results from one environment to another [8].

“Team size” received little focus. A startup with 5 employees have different needs and challenges from a startup with more than 150 employees (e.g., communication needs) [78]. Even though team size will affect engineering practices to a large degree, too few of the primary papers presented the team size of the startups investigated. More research is needed to understand how software engineering practices change according to team size, and to what extent team size should be part of a unique definition of startups. We found that the usual
1090 number of employees in investigated startups was 2-25. The number depends on their respective lifecycle stage or the age of the company. A startup usually starts with 2-6 founders, but as the business scales, more employees are required. This will, in turn, affect the startup’s need for software processes. As to this, we emphasize that researchers must be aware of which describing concepts that
1100 are relevant for the startups they are investigating, and that they specify this in their work. More consistent focus on the situational context is a vital step towards a more coherent body of knowledge.

The research track of Unterkalmsteiner et al. [1] aims at developing a software startup context model that would allow a coherent characterization of
1105 software startups. Since there is no agreement on a standard definition, it is challenging to provide coherent contributions to the research area.

6. Conclusion

In this study, we have applied a systematic mapping method to analyze the literature related to software startup engineering. A total number of 74 primary

1110 papers (in which 27 papers are newly selected) were extracted and synthesized.
Our study, along with the previous mapping studies, constitute a merging of the
primary literature within the field for the period 1994-2017, including the focus
and relative strength of research, and the effort that's been made to characterize
the software startup context.

1115 The contribution of this mapping study is two-fold. Firstly, the study pro-
vides a comprehensive view of software startups for Software Engineering re-
searchers. Possible research gaps are derived for future studies. Secondly, the
study provides a map of the contextual setting of investigated startups, inferring
the applicability area of empirical findings. This can help to compare and to
1120 generalize future research in software startups.

Regards to RQ1, most found software startup research between 2013-2017,
are conducted within software engineering management and software engineer-
ing process, while software design and software requirements have received most
attention between 1994-2013. For the period 2013-2017, software design received
1125 fewer contributions compared to that in 1994-2013, illustrating a change of re-
search direction. The knowledge areas software engineering models and meth-
ods, software quality, and software testing have received little attention from the
research community during the period 1994-2017. Apart from these findings,
we emphasize the need for more research within all knowledge areas. For the
1130 period 2013-2017 software configuration management and software maintenance
were not covered at all. As to this, it seems that some of the knowledge areas
aren't directly relevant to the startup context. Future mappings should instead
use the newly established research themes of Unterkalmsteiner et al. [1].

Regards to RQ2, we found an increased rigour of primary studies after 2013
1135 in comparison with studies found in 1994-2013. While it is still not clear
about the transformation of research results to startup practitioners, startup
researchers seem to increase the focus on conducting high-quality research. The
increased importance of startups has been an important factor to highlight the
need for more research. As startups generally use ad-hoc or opportunistic de-
1140 velopment methods, practices of startups can be different, meaning that more
evidence is needed to generalize work practices to all startups.

Regards to RQ3, we identify a coherent set of concepts that represent the
startup context, (1) Innovation/innovative, (2) Lack of resources, (3) Uncer-
tainty, (4) Time-pressure, (5) Small team, (6) Highly reactive, (7) Rapidly
1145 evolving. Additionally, aspects like (1) team size, (2) product orientation, (3)
number of active years/life cycle stage, (4) number of investigated startups, (5)
location, and (6) development method are important to describe sufficiently to
be able to transfer results from one environment to another. As only 14 of the
primary papers between 2013-2017 provided adequate descriptions, and all pri-
1150 mary papers showed an overall inconsistent use of describing thematic concepts,
we see a need for a more comprehensive endeavor to describe the engineering
context of startups.

Several threats to validity were considered, including the selection of papers,
the use of few online bibliographic databases, the selection of keywords, and
1155 the coarse-grained classification used for the quality assessment. To ensure the

selection process was unbiased, the selection criteria were developed in advance, also the first, second and third author were involved in the selection process. Both the use of few online bibliographic databases and the identified keywords and search terms might have lead to relevant papers being omitted. This risk
1160 was mitigated by performing an additional manual search. For the quality assessment, it is likely that the use of only two points have caused the papers to obtain a higher rigour than they would have if a more fine-grained assessment method had been used.

Future work can focus on certain research themes, such as startup evolution
1165 models and human aspects, and consolidate the contextual factors of software startups. More work should be conducted for specific business contexts, such as startups that are part of incubators and bigger business ecosystems. As a next step, we seek to address engineering practices in startups who deliver both hardware and software, as no prior studies have been entirely dedicated towards
1170 their specific challenges and demands.

Appendix A.

Appendix A presents the classification schema (A.7), which includes the classification of each primary paper. Table A.8 and table A.9 explain some of the attributes of the classification schema in more detail.

ID	Research Method	Contribution Type	Knowledge Area	Pertinence	Term for startup	Incubator context	Publisher
30	Case study	Lessons learned	Process	Full	Startup	No	Penn University
51	Experiment	Lessons learned	Professional Practice, Management, Quality	Partial	Start-up	No	QUATIC
79		Framework	Professional Practice	Full	Start-up	No	ACM
69	Experiment	Guidelines	Process	Full	Start-up	No	ENASE
74	Case study	Theory	Process, Management, Quality	Partial	Startup	No	Springer
59	Survey	Tool	Construction	Full	Startup	No	Springer
56	Case study	Model	Process, Management	Full	Startup	No	ACM
67	Case study	Lessons learned	Process	Full	Very Small Company	No	Springer
31		Guidelines	Process	Partial	Startup	No	Springer
1		Advice	Process, Management, Professional Practice, Construction, Requirements, Quality, Testing	Full	Startup	No	EISEJ
76		Advice	Quality, Construction	Full	Startup	No	Springer
73	Case study	Lessons learned	Process, Management	Partial	Very Small Enterprise	No	IEEE
5	Design and creation	Model	Models and Methods	Full	Startup	No	IEEE
44	Case study	Lessons learned	Management, Requirements	Full	Startup	No	Springer
28	Case study	Lessons learned	Management, Design, Construction	Full	Startup	No	Springer
45	Case study	Model	Methods and Models, Management	Full	Startup	No	IEEE
46	Case study	Advice	Management, Process	Full	Startup	No	EASE
29	Case study	Lessons learned	Management, Testing	Full	Startup	No	Springer
47	Case study	Theory	Management, Process	Full	Startup	No	Springer
17	Case study	Lessons learned	Management, Design	Full	Startup	No	Springer
65	Case study	Lessons learned	Process, Testing	Full	Startup	Yes	KSI Graduate School
72	Survey	Lessons learned	Professional Practice	Full	Startup	No	Springer
14	Case study	Lessons learned	Requirements	Full	Startup	No	IEEE
66	Case study	Model	Professional Practice	Full	Startup	Yes	IEEE
77		Framework	Quality	Full	Startup	No	IEEE
13	Case study	Lessons learned	Requirements	Full	Startup	No	IEEE
68	Case study	Advice	Process	Full	Start-up	No	Springer

Table A.7: Classification Schema

1175 *Research Methods*

Research Method	Description
Survey	Obtain the same kinds of data from a large group of people in a standardized, systematic way to find patterns through statistics.
Design and creation	Development of new IT products or artifacts, or even a model or method.
Experiment	Investigation of cause and effect relationships through hypotheses-testing and proofs. Typically "before" and "after" measurements.
Case study	Focusing on one instance of the "thing" being investigated to obtain a rich, detailed insight into the case and its complex relationships and processes.
Action research	Plan to do something in real life, do it, and reflect on the outcome and learnings.
Ethnography	Focusing on understanding the ways of seeing a specific group of people through field research.

Table A.8: Research Methods [\[57\]](#)

Contribution Types

Contribution Type	Description
Model	Representation of an observed reality by concepts or related concepts after a conceptualization process
Theory	Construction of cause-effect relationships from determined results
Framework/methods	Models related to constructing software or managing development processes
Guidelines	List of advices, synthesis of the obtained research results
Lessons learned	Set of outcomes, directly analyzed from the obtained research result
Advice/implications	Discursive, and generic recommendation, deemed from personal opinions
Tool	Technology, program or application used to create, debug, maintain or support development processes

Table A.9: Contribution Types [\[7\]](#)

Appendix B.

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score
[30]	1	1	0	1	1	1	0	0	1	0	6
[51]	1	1	1	1	1	1	1	0	1	0	8
[69]	1	1	1	1	1	1	1	0	1	0	8
[74]	1	1	1	1	1	1	1	0	1	1	9
[59]	1	1	0	0	0	0	0	0	1	0	3
[56]	1	1	1	1	1	0	0	1	1	1	8
[67]	1	1	1	1	0	1	1	0	1	1	8
[73]	1	1	1	1	1	1	1	0	1	0	8
[5]	1	1	1	1	1	1	1	1	1	1	10
[65]	1	1	1	1	1	1	1	0	1	1	9
[72]	1	1	1	1	1	1	1	0	1	1	9
[14]	1	1	1	0	1	0	1	1	1	1	8
[66]	1	1	1	0	1	1	1	0	1	1	8
[68]	1	1	1	1	1	1	1	0	1	0	8
[44]	1	1	1	0	1	1	1	0	1	1	8
[28]	1	1	1	1	1	1	1	0	1	1	9
[45]	1	1	1	1	1	1	1	1	1	1	10
[46]	1	1	1	1	1	1	1	1	1	1	10
[29]	1	1	1	1	1	1	1	1	1	1	10
[47]	1	1	1	0	1	1	1	0	1	0	7
[17]	1	1	1	1	1	1	1	1	1	1	10
[13]	1	1	1	1	1	0	1	1	1	0	8

Table B.10: Quality assessment 2013-2017, based on table 3 in Nguyen-Duc et al. [48]

Recurring Themes	Explanation
Lack of resources	Economical, human, and physical resources are very scarce or limited.
Highly reactive	Startups can react very fast to changed market conditions, technologies, or changed customer demands.
Innovative	The startups focus on innovative market segments, most likely where they can disrupt markets.
Uncertainty	The ecosystem in which the startups operate within are very uncertain, wrt. customers, competition, technologies.
Rapidly evolving	Startups' objective is to grow and scale rapidly.
Time-pressure	The market and environment demands fast product releases and constant pressure.
Third party dependency	Startups need to rely on external entities and technologies in their lack of time and resources.
Small team	The startup consist of a small number of individuals.
One product	The startup is only concerned with the development of one product.
Low-experienced team	Maximum five years of experience or newly graduated students.
Highly risky	The failure rate of startups is high.
New company	The company is newly established.
Flat organization	All individuals in the company have shared responsibility, no high-management.
Not self-sustained	External funding is required, especially in the early-stages.
Little working/operating history	There is a lack of organizational culture as the startup is young.

Table B.11: Explanation of recurring themes, based on table 6 in Paternoster et al. [7]

References

- 1180 [1] M. Unterkalmsteiner, P. Abrahamsson, X. F. Wang, N. D. Anh, S. Shah, S. S. Bajwa, G. H. Baltés, K. Conboy, E. Cullina, D. Dennehy, H. Edison, C. Fernandez-Sanchez, J. Garbajosa, T. Gorschek, E. Klotins, L. Hokkanen, F. Kon, I. Lunesu, M. Marchesi, L. Morgan, M. Oivo, C. Selig, P. Seppanen, R. Sweetman, P. Tyrvainen, C. Ungerer, A. Yague, [Software startups - a research agenda](#), *E-Informatica Software Engineering Journal* 10 (1) (2016) 89–123. [doi:10.5277/e-Inf160105](#).
 1185 URL [<GotoISI>://WOS:000387014900006](#)
- [2] M. Marmer, B. L. Herrmann, E. Dogrultan, R. Berman, C. Eesley, S. Blank, Startup genome report extra: Premature scaling, Vol. 10, 2011.

- 1190 [3] M. Crowne, Why software product startups fail and what to do about it. evolution of software product development in startup companies, in: Engineering Management Conference, 2002. IEMC'02. 2002 IEEE International, Vol. 1, IEEE, 2002, pp. 338–343.
- 1195 [4] C. Giardino, S. S. Bajwa, X. Wang, P. Abrahamsson, Key challenges in early-stage software startups, in: International Conference on Agile Software Development, Springer, 2015, pp. 52–63.
- [5] C. Giardino, N. Paternoster, M. Unterkalmsteiner, T. Gorschek, P. Abrahamsson, Software development in startup companies: The greenfield startup model, IEEE Transactions on Software Engineering 42 (6) (2016) 585–604. doi:10.1109/TSE.2015.2509970.
1200 URL <http://dx.doi.org/10.1109/TSE.2015.2509970>
- [6] S. M. Sutton Jr, Role of process in a software start-up, IEEE Software 17 (4) (2000) 33–39. doi:10.1109/52.854066.
URL <http://dx.doi.org/10.1109/52.854066>
- 1205 [7] N. Paternoster, C. Giardino, M. Unterkalmsteiner, T. Gorschek, P. Abrahamsson, Software development in startup companies: A systematic mapping study, Information and Software Technology 56 (10) (2014) 1200–18. doi:10.1016/j.infsof.2014.04.014.
URL <http://dx.doi.org/10.1016/j.infsof.2014.04.014>
- 1210 [8] E. Klotins, M. Unterkalmsteiner, T. Gorschek, Software Engineering Knowledge Areas in Startup Companies: A Mapping Study, Vol. 210 of Lecture Notes in Business Information Processing, 2015, pp. 245–257. doi:10.1007/978-3-319-19593-3_22.
URL http://dx.doi.org/10.1007/978-3-319-19593-3_22
- [9] P. Bourque, R. E. Fairley, Guide to the software engineering body of knowledge (SWEBOK (R)): Version 3.0, IEEE Computer Society Press, 2014.
- 1215 [10] G. Coleman, R. V. O'Connor, An investigation into software development process formation in software start-ups, Journal of Enterprise Information Management 21 (6) (2008) 633–648. doi:10.1108/17410390810911221.
1220 URL <https://www.scopus.com/inward/record.uri?eid=2-s2.0-55349133834&doi=10.1108/2f17410390810911221&partnerID=40&md5=9a7aca62e6f24c6416fd3034dbb66b0a>
- [11] C. Giardino, M. Unterkalmsteiner, N. Paternoster, T. Gorschek, P. Abrahamsson, What do we know about software development in startups?, IEEE Software 31 (5) (2014) 28–32. doi:10.1109/MS.2014.129.
1225 URL <http://dx.doi.org/10.1109/MS.2014.129>
- [12] E. Ries, The lean startup: How today's entrepreneurs use constant innovation to create radically successful businesses, Crown Books, 2011.

- 1230 [13] R. Chanin, L. Pompermaier, K. Fraga, A. Sales, R. Prikladnicki, Applying customer development for software requirements in a startup development program, in: Proceedings of the 1st International Workshop on Software Engineering for Startups, IEEE Press, 2017, pp. 2–5.
- 1235 [14] U. Rafiq, S. S. Bajwa, W. Xiaofeng, I. Lunesu, Requirements elicitation techniques applied in software startups, in: 2017 43rd Euromicro Conference on Software Engineering and Advanced Applications (SEAA), 30 Aug.-1 Sept. 2017, 2017 43rd Euromicro Conference on Software Engineering and Advanced Applications (SEAA), IEEE Computer Society, 2017, pp. 141–4. doi:10.1109/SEAA.2017.73
URL <http://dx.doi.org/10.1109/SEAA.2017.73>
- 1240 [15] J. Bosch, H. H. Olsson, J. Björk, J. Ljungblad, The early stage software startup development model: a framework for operationalizing lean principles in software startups, in: Lean Enterprise Software and Systems, Springer, 2013, pp. 1–15.
- [16] S. Blank, Why the lean start-up changes everything, Harvard business review 91 (5) (2013) 63–72.
- 1245 [17] A. Nguyen-Duc, X. Wang, P. Abrahamsson, What influences the speed of prototyping? an empirical investigation of twenty software startups, in: International Conference on Agile Software Development, Springer, 2017, pp. 20–36.
- 1250 [18] L. Karlsson, Dahlstedt, J. N. och Dag, B. Regnell, A. Persson, Challenges in market-driven requirements engineering-an industrial interview study, in: Eighth International Workshop on Requirements Engineering: Foundation for Software Quality, 2002.
- 1255 [19] E. Carmel, Time-to-completion in software package startups, in: 1994 Proceedings of the Twenty-Seventh Hawaii International Conference on System Sciences, 1994.
- [20] A. Dahlstedt, Study of current practices in market-driven requirements engineering, in: Third Conference for the Promotion of Research in IT at New Universities and University Colleges in Sweden, 2003.
- 1260 [21] M. Keil, E. Carmel, Customer-developer links in software development, Communications of the ACM 38 (5) (1995) 33–44.
- [22] C. Alves, S. Pereira, J. Castro, A study in market-driven requirements engineering.
- [23] S. Blank, The four steps to the epiphany: successful strategies for products that win, BookBaby, 2013.

- 1265 [24] S. A. Alvarez, J. B. Barney, Discovery and creation: Alternative theories
of entrepreneurial action, *Strategic entrepreneurship journal* 1 (1-2) (2007)
11–26.
- [25] S. D. Sarasvathy, Causation and effectuation: Toward a theoretical shift
from economic inevitability to entrepreneurial contingency, *Academy of
1270 management Review* 26 (2) (2001) 243–263.
- [26] A. Maurya, *Running lean: iterate from plan A to a plan that works,* ”
O’Reilly Media, Inc.”, 2012.
- [27] J. P. Womack, D. T. Jones, D. Roos, *Machine that changed the world,*
Simon and Schuster, 1990.
- 1275 [28] A. Nguyen-Duc, P. Abrahamsson, Minimum viable product or multiple
facet product? the role of mvp in software startups, in: *International
Conference on Agile Software Development*, Springer, 2016, pp. 118–130.
- [29] S. S. Bajwa, X. Wang, A. N. Duc, P. Abrahamsson, “failures” to be cele-
brated: an analysis of major pivots of software startups, *Empirical Software
1280 Engineering* 22 (5) (2017) 2373–2408.
- [30] A. Yau, C. Murphy, Is a rigorous agile methodology the best development
strategy for small scale tech startups?
- [31] A. I. Wasserman, Low ceremony processes for short lifecycle projects, in:
Managing Software Process Evolution, Springer, 2016, pp. 1–13.
- 1285 [32] M. Kuhrmann, J. Münch, I. Richardson, A. Rausch, H. Zhang, *Managing
Software Process Evolution: Traditional, Agile and Beyond—How to Handle
Process Change*, Springer, 2016.
- [33] M. Tanabian, B. ZahirAzami, Building high-performance team through ef-
fective job design for an early stage software start-up, in: *Engineering Man-
agement Conference*, 2005. Proceedings. 2005 IEEE International, Vol. 2,
1290 IEEE, 2005, pp. 789–792.
- [34] S. Chorev, A. R. Anderson, Success in israeli high-tech start-ups; critical
factors and process, *Technovation* 26 (2) (2006) 162–174.
- [35] M. Kakati, Success criteria in high-tech new ventures, *Technovation* 23 (5)
1295 (2003) 447–457.
- [36] N. Tripathi, E. Annanpera, M. Oivo, K. Liukkunen, [Exploring Processes
in Small Software Companies: A Systematic Review](#), Vol. 609 of *Com-
munications in Computer and Information Science*, 2016, pp. 150–165.
[doi:10.1007/978-3-319-38980-6_12](https://doi.org/10.1007/978-3-319-38980-6_12)
1300 URL [<GotoISI>://WOS:000382651100012](https://www.wos.com/000382651100012)

- [37] G. Coleman, R. O'Connor, Investigating software process in practice: A grounded theory perspective, *Journal of Systems and Software* 81 (5) (2008) 772–784.
- 1305 [38] G. Coleman, R. O'Connor, Using grounded theory to understand software process improvement: A study of irish software product companies, *Information and Software Technology* 49 (6) (2007) 654–667.
- [39] M. Kajko-Mattsson, N. Nikitina, [From knowing nothing to knowing a little: Experiences gained from process improvement in a start-up company](#), in: *International Conference on Computer Science and Software Engineering, CSSE 2008, December 12, 2008 - December 14, 2008, Vol. 2 of Proceedings - International Conference on Computer Science and Software Engineering, CSSE 2008, IEEE Computer Society, 2008*, pp. 617–621. [doi:10.1109/CSSE.2008.1370](#)
URL <http://dx.doi.org/10.1109/CSSE.2008.1370>
- 1310
- 1315 [40] B. Kitchenham, Procedures for performing systematic reviews, Keele, UK, Keele University 33 (2004) (2004) 1–26.
- [41] K. Petersen, R. Feldt, S. Mujtaba, M. Mattsson, Systematic mapping studies in software engineering, in: *EASE*, Vol. 8, 2008, pp. 68–77.
- [42] C. Wohlin, Guidelines for snowballing in systematic literature studies and a replication in software engineering, in: *Proceedings of the 18th international conference on evaluation and assessment in software engineering*, ACM, 2014, p. 38.
- 1320
- [43] F. Shull, J. Singer, D. I. Sjøberg, *Guide to advanced empirical software engineering*, Springer, 2007.
- 1325 [44] S. S. Bajwa, X. Wang, A. N. Duc, P. Abrahamsson, How do software startups pivot? empirical results from a multiple case study, in: *International Conference of Software Business*, Springer, 2016, pp. 169–176.
- [45] A. Nguyen-Duc, S. M. A. Shah, P. Abrahamsson, Towards an early stage software startups evolution model, in: *Software Engineering and Advanced Applications (SEAA), 2016 42th Euromicro Conference on, IEEE, 2016*, pp. 120–127.
- 1330
- [46] A. N. Duc, P. Abrahamsson, Exploring the outsourcing relationship in software startups: A multiple case study, in: *Proceedings of the 21st International Conference on Evaluation and Assessment in Software Engineering*, ACM, 2017, pp. 134–143.
- 1335
- [47] A. Nguven-Duc, Y. Dahle, M. Steinert, P. Abrahamsson, Towards understanding startup product development as effectual entrepreneurial behaviors, in: *International Conference on Product-Focused Software Process Improvement*, Springer, 2017, pp. 265–279.

- 1340 [48] A. Nguyen-Duc, D. S. Cruzes, R. Conradi, The impact of global disper-
sion on coordination, team performance and software quality—a systematic
literature review, *Information and Software Technology* 57 (2015) 277–294.
- [49] M. Ivarsson, T. Gorschek, A method for evaluating rigor and industrial
1345 relevance of technology evaluations, *Empirical Software Engineering* 16 (3)
(2011) 365–395.
- [50] X. Zhou, Y. Jin, H. Zhang, S. Li, X. Huang, A map of threats to validity
of systematic literature reviews in software engineering, in: *Software En-
gineering Conference (APSEC), 2016 23rd Asia-Pacific, IEEE, 2016*, pp.
153–160.
- 1350 [51] C. Y. Laporte, R. V. O’Connor, Ieee, [Systems and software engineering
standards for very small entities: Implementation and initial results](#), 2014
9th International Conference on the Quality of Information and Communi-
cations Technology (QUATIC) (2014) 38–47 [doi:10.1109/quatic.2014.
12](#).
- 1355 URL [<GotoISI>://WOS:000364237700005](#)
- [52] E. Klotins, M. Unterkalmsteiner, T. Gorschek, Software engineering in
start-up companies: An analysis of 88 experience reports, *Empirical Soft-
ware Engineering* (2018) 1–35.
- [53] K. Kautz, Improvement in very small enterprises: Does it pay off, *Softw.
1360 Process Improv. Pr* 226 (1988) (2000) 209–226.
- [54] S. Jansen, S. Brinkkemper, I. Hunink, C. Demir, Pragmatic and oppor-
tunistic reuse in innovative start-up companies, *IEEE software* 25 (6).
- [55] S. Shakir, J. Nørbjerg, It project management in very small software com-
panies: A case of pakistan, in: *Americas Conference on Information Sys-
1365 tems, 2013*, pp. 1–8.
- [56] A. Nguyen-Duc, P. Seppanen, P. Abrahamsson, [Hunter-gatherer cycle: A
conceptual model of the evolution of software startups](#), in: *International
Conference on Software and Systems Process, ICSSP 2015, August 24, 2015
- August 26, 2015, Vol. 24-26-August-2015 of ACM International Confer-
1370 ence Proceeding Series, Association for Computing Machinery, 2015*, pp.
199–203. [doi:10.1145/2785592.2795368](#).
URL [http://dx.doi.org/10.1145/2785592.2795368](#)
- [57] B. J. Oates, *Researching information systems and computing*, Sage, 2005.
- 1375 [58] M. Shaw, Writing good software engineering research papers, in: *Software
Engineering, 2003. Proceedings. 25th International Conference on, IEEE,
2003*, pp. 726–736.

- [59] H. Edison, D. Khanna, S. S. Bajwa, V. Brancaleoni, L. U. Bellettati, [Towards a software tool portal to support startup process](#), in: 16th International Conference on Product-Focused Software Process Improvement, PROFES 2015, December 2, 2015 - December 4, 2015, Vol. 9459 of Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), Springer Verlag, 2015, pp. 577–583. [doi:10.1007/978-3-319-26844-6_43](#).
URL http://dx.doi.org/10.1007/978-3-319-26844-6_43
- 1380
- [60] M. Häsel, T. Kollmann, N. Breugst, It competence in internet founder teams, *Business & Information Systems Engineering* 2 (4) (2010) 209–217.
- 1385
- [61] R. Stanfill, T. Astleford, Improving entrepreneurship team performance through market feasibility analysis, early identification of technical requirements, and intellectual property support, in: *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, 2007.
- 1390
- [62] K. Kuvinka, Scrum and the single writer, *Proceedings of Technical Communication Summit* (2011) 18–19.
- [63] S.-l. Lai, Chinese entrepreneurship in the internet age: Lessons from alibaba.com, *World Academy of Science, Engineering and Technology* 72 (2010) 405–411.
- 1395
- [64] D. B. Yoffie, M. A. Cusumano, Building a company on internet time: Lessons from netscape, *California Management Review* 41 (3) (1999) 8–28.
- [65] L. Pompermaier, R. Chanin, A. Sales, K. Fraga, R. Prikladnicki, [An empirical study on software engineering and software startups: Findings from cases in an innovation ecosystem](#), in: 29th International Conference on Software Engineering and Knowledge Engineering, SEKE 2017, July 5, 2017 - July 7, 2017, *Proceedings of the International Conference on Software Engineering and Knowledge Engineering, SEKE, Knowledge Systems Institute Graduate School*, 2017, pp. 48–51. [doi:10.18293/SEKE2017-115](#).
URL <http://dx.doi.org/10.18293/SEKE2017-115>
- 1400
- [66] R. Souza, K. Malta, E. S. D. Almeida, [Software engineering in startups: A single embedded case study](#), in: 1st IEEE/ACM International Workshop on Software Engineering for Startups, SoftStart 2017, May 21, 2017, *Proceedings - 2017 IEEE/ACM 1st International Workshop on Software Engineering for Startups, SoftStart 2017, Institute of Electrical and Electronics Engineers Inc.*, 2017, pp. 17–23. [doi:10.1109/SoftStart.2017.2](#).
URL <http://dx.doi.org/10.1109/SoftStart.2017.2>
- 1410
- [67] M.-L. Sánchez-Gordón, R. V. O'Connor, Understanding the gap between software process practices and actual practice in very small companies, *Software Quality Journal* 24 (3) (2016) 549–570.
- 1415

- 1420 [68] G. Marks, R. V. O'Connor, P. M. Clarke, The impact of situational context on the software development process – a case study of a highly innovative start-up organization, Vol. 770, 2017, pp. 455–466. [doi:10.1007/978-3-319-67383-7_33](https://doi.org/10.1007/978-3-319-67383-7_33).
- [69] C. Y. Laporte, R. V. O'Connor, L. H. G. Paucar, [Software engineering standards and guides for very small entities: Implementation in two start-ups](#), 2015, pp. 5–15.
URL <https://www.scopus.com/inward/record.uri?eid=2-s2.0-84933558276&partnerID=40&md5=02b5f237bb268c0133caa7c6cb17a44a>
- 1425 [70] P. Clarke, R. V. O'Connor, The situational factors that affect the software development process: Towards a comprehensive reference framework, *Information and Software Technology* 54 (5) (2012) 433–447.
- 1430 [71] ISO, <https://www.iso.org/home.html>, access date: 2017-11-12 (2017).
[link]
URL <https://www.iso.org/home.html>
- [72] J. Pantiuchina, M. Mondini, D. Khanna, X. Wang, P. Abrahamsson, [Are software startups applying agile practices? the state of the practice from a large survey](#), in: 18th International Conference on Agile Software Development, XP 2017, May 22, 2017 - May 26, 2017, Vol. 283 of Lecture Notes in Business Information Processing, Springer Verlag, 2017, pp. 167–183. [doi:10.1007/978-3-319-57633-6_11](https://doi.org/10.1007/978-3-319-57633-6_11).
URL http://dx.doi.org/10.1007/978-3-319-57633-6_11
- 1440 [73] C. Y. Laporte, R. V. O'Connor, Implementing process improvement in very small enterprises with iso/iec 29110: A multiple case study analysis, in: *Quality of Information and Communications Technology (QUATIC)*, 2016 10th International Conference on the, IEEE, 2016, pp. 125–130.
- 1445 [74] J. Yli-Huumo, T. Rissanen, A. Maglyas, K. Smolander, L.-M. Sainio, [The relationship between business model experimentation and technical debt](#), in: 6th International Conference on Software Business, IC-SOB 2015, June 10, 2015 - June 12, 2015, Vol. 210 of Lecture Notes in Business Information Processing, Springer Verlag, 2015, pp. 17–29. [doi:10.1007/978-3-319-19593-3_2](https://doi.org/10.1007/978-3-319-19593-3_2).
URL http://dx.doi.org/10.1007/978-3-319-19593-3_2
- 1450 [75] S. McConnell.
- [76] H. Terho, S. Suonsyrja, K. Systa, [The developers dilemma: Perfect product development or fast business validation?](#), in: 17th International Conference on Product-Focused Software Process Improvement, PROFES 2016, November 24, 2016 - November 26, 2016, Vol. 10027 LNCS of Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), Springer Verlag, 2016, pp.
- 1455

571–579. [doi:10.1007/978-3-319-49094-6_42](https://doi.org/10.1007/978-3-319-49094-6_42).

URL http://dx.doi.org/10.1007/978-3-319-49094-6_42

- 1460 [77] M. Chicote, [Startups and technical debt: Managing technical debt with visual thinking](#), in: 2017 IEEE/ACM 1st International Workshop on Software Engineering for Startups (SoftStart), 21 May 2017, 2017 IEEE/ACM 1st International Workshop on Software Engineering for Startups (SoftStart). Proceedings, IEEE Computer Society, 2017, pp. 10–11. [doi:10.1109/SoftStart.2017.6](https://doi.org/10.1109/SoftStart.2017.6).

1465 URL <http://dx.doi.org/10.1109/SoftStart.2017.6>

- [78] R. Deias, G. Mugheddu, O. Murru, Introducing xp in a start-up, in: Proceedings 3rd International Conference on eXtreme Programming and Agile Processes in Software Engineering (XP), 2002, pp. 62–65.

- 1470 [79] V.-P. Eloranta, [Towards a pattern language for software start-ups](#), in: 19th European Conference on Pattern Languages of Programs, EuroPLoP 2014, July 9, 2014 - July 13, 2014, Vol. 09-13-July-2014 of ACM International Conference Proceeding Series, Association for Computing Machinery, 2014. [doi:10.1145/2721956.2721965](https://doi.org/10.1145/2721956.2721965).

1475 URL <http://dx.doi.org/10.1145/2721956.2721965>