



Revealing the state of the art of large-scale agile development research: A systematic mapping study

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ABSTRACT

Context: Success with agile methods in the small scale has led to an increasing adoption also in large development undertakings and organizations. Recent years have also seen an increasing amount of primary research on the topic, as well as a number of systematic literature reviews. However, there is no systematic overview of the whole research field.

Objective: This work identifies, classifies, and evaluates the state of the art of research in large-scale agile development.

Methods: We conducted a systematic mapping study and rigorously selected 136 studies. We designed a classification framework and extracted key information from the studies. We synthesized the obtained data and created an overview of the state of the art.

Results: This work contributes with (i) a description of large-scale agile endeavors reported in the industry, (ii) a systematic map of existing research in the field, (iii) an overview of influential studies, (iv) an overview of the central research themes, and (v) a research agenda for future research.

Conclusion: This study portrays the state of the art in large-scale agile development and offers researchers and practitioners a reflection of the past thirteen years of research and practice on the large-scale application of agile methods.

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1. Introduction

Contemporary business environments are characterized by high unpredictability due to rapidly shifting customer demands and technological advancements, implying that flexibility, adaptability, and learning are crucial to business success (Orlikowski, 1996). Over the past decades, software has become an integral part of many products and services (Petersen and Wohlin, 2010a). To react quickly to changing environments and fluctuating customer requirements, the agile movement emerged in the 1990s, leading to the creation of the Agile Manifesto¹ and many agile methods, e.g., Extreme Programming (XP) (Beck, 2000) and Scrum (Schwaber and Beedle, 2002; Kettunen, 2007; Petersen and Wohlin, 2010a). Agile methods were originally designed for small, co-located, and self-organizing teams that produce software in close collaboration with business customers, using regular feedback and rapid development iterations (Dingsøyr et al., 2018b;

Dikert et al., 2016). The successful application of agile methods in small projects inspired companies to increasingly adopt agile methods also in large-scale projects and organizations (Dingsøyr et al., 2014). During the last decade, agile methods have been extended to better fit large-scale settings. Several scaling frameworks have been created both by some custodians of existing agile methods and by others who have worked with companies in scaling agile methods to their settings (Uludağ et al., 2021). As the frameworks claim to provide off-the-shelf solutions to the problems of scaling, their adoption has rapidly increased in practice, as confirmed by the latest State of Agile survey (Digital.ai, 2020). The survey shows that many large software-intensive companies have adopted scaling frameworks to address challenges accompanied by the scaling of agile methods (Carroll and Conboy, 2019; Alqudah and Razali, 2016). While there are more than 20 available frameworks (Uludağ et al., 2021), the most popular ones are (Digital.ai, 2020): Scaled Agile Framework (SAFe) (Scaled Agile Inc., 2022), Large-Scale Scrum (LeSS) (The LeSS Company B.V., 2022), and Disciplined Agile Delivery (DAD) (Ambler and Lines, 2012).

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¹ <https://agilemanifesto.org/>, last accessed on: 19-04-2022.

As the popularity of applying agile methods at scale has increased in the industry, scientific research on the topic has emerged in recent years. Eleven years ago, at the International Conference on Agile Software Development, industrial practitioners were asked to create a backlog of topics they think should be studied. They voted “Agile and large projects” as a top burning research question (Freudenberg and Sharp, 2010). After that, nine International Workshops on Large-Scale Agile Development at the yearly International Conferences on Agile Software Development have gathered researchers and practitioners to discuss recent large-scale agile development studies and create research agendas for future research on that area (cf. Dingsøyr and Moe, 2013; Moe and Dingsøyr, 2017). In recent years, research publications on large-scale agile have been published at scientific conferences and journals, and the body of knowledge has grown immensely (cf. Dikert et al., 2016; Edison et al., 2021). Although scientific articles on large-scale agile development are mainly primary studies, we also identified several secondary studies that synthesize the scientific knowledge on large-scale agile development related to specific topics, e.g., the systematic literature review on “challenges and success factors for large-scale agile transformations” (Dikert et al., 2016). A steadily growing number of primary studies is a valuable indicator of the increasing maturity of a research field. It leads to a critical tipping point when secondary studies can be conducted, which then facilitates the aggregation of the results of the primary studies. As the research area of large-scale agile development matures and the number of studies increases, there is a need to systematically identify, analyze, and classify the state of the art of this research field. While the number of primary studies is sufficient, so far, no systematic mapping study has been published to provide a comprehensive overview of the state of research in this area. This mapping study aims to close this gap and provide an overview of the research activities pertaining to large-scale agile development. The main contributions of this study are as follows:

- A description of large-scale agile endeavors and their characteristics reported in the industry,
- A systematic map classifying, comparing, and evaluating existing research on large-scale agile development,
- An overview of the most influential studies on large-scale agile development,
- An overview of the central research themes and main findings on large-scale agile development, and
- A research agenda consisting of a detailed description of research gaps and a list of open research questions in large-scale agile development.

The remainder of this paper is structured as follows. Section 2 presents background and related work. Section 3 portrays the procedure of the systematic mapping study. Section 4 shows the results of this study. Section 5 discusses the results. Section 6 describes the threats to validity. Section 7 concludes the paper along with remarks on future research.

2. Background and related work

This section provides the background on agile software development and large-scale agile development and gives an overview of related work, including other secondary studies.

2.1. Agile software development

Software development methods have undergone a dramatic evolution from traditional sequential development approaches to more flexible and adaptive development approaches due to

the market's increasing demands and customer requirements volatility (Petersen and Wohlin, 2010a). To address these needs, many companies have started to adopt agile software development methods (Petersen and Wohlin, 2009). Various software practitioners introduced several agile methods in recent years, e.g., the Crystal Method, the Dynamic System Development Method, and the Feature-Driven Development Method, that comprise a set of iterative and incremental methods based on specific values and principles defined in the Agile Manifesto (Abrahamsson et al., 2003). Currently, the most widely adopted agile methods in industry are Scrum and XP (Hamed and Abushama, 2013). These methods have aroused great interest both in practice and academia (Abrahamsson et al., 2017).

Agile methods have received both acceptance and criticism in the industry (Boehm, 2002). On the one hand, they have proven to be successful in improving quality (Schmidt et al., 2014), productivity (Dybå and Dingsøyr, 2009), and customer satisfaction (Dybå and Dingsøyr, 2009). On the other hand, there is concern that these methods may not be suitable for large-scale environments (Dybå and Dingsøyr, 2009). Dybå and Dingsøyr (2009) note that there is evidence that suggests combining agile and traditional methods, i.e., hybrid methods, in large undertakings and recommends that practitioners should carefully examine and compare project characteristics with the required characteristics of the suitable agile method(s). Previous literature has also reported on the success of hybrid approaches (Mahanti, 2006), e.g., recent research by Klünder et al. (2019) concludes that projects devising hybrid methods have about a 5% better chance of achieving their goals.

According to Digital.ai (2020), companies adopt agile methods to accelerate software delivery, manage changing priorities, increase productivity, improve alignment between business and IT, and enhance quality, to name a few. However, adopting agile methods is not easy, as agile methods do not rely solely on the appropriate application of individual tools or practices but rather often demand a holistic way of thinking and mindset. Thus, the adoption of agile methods often requires a change in the entire organizational culture (Misra et al., 2010). Developing an agile mindset and changing the company's culture takes time and effort, and if this effort is neglected, the organization can fall back into old habits and fail to reap the full benefits of agility (Koutsikouri et al., 2020).

2.2. Large-scale agile development

The success of agile methods for small, co-located teams has incited companies to increasingly apply agile practices to large-scale projects (Dingsøyr et al., 2018b; Dikert et al., 2016; Putta et al., 2018). However, the large-scale adoption of agile methods has proven to be very challenging (Dybå and Dingsøyr, 2008). The challenges of adopting agile practices at large-scale are partly related to the organization's size, as the difficulties of adopting agile methods increase with the size of the organization, i.e., in large organizations, products are more complex, and the inter-dependencies between teams are greater than in smaller organizations (Dybå and Dingsøyr, 2008; Ambler, 2007), leading to inertia and slowing down the change process (Livermore, 2008). Another challenge in large organizations is the need for coordination and communication between multiple teams and also between different organizational units that often do not work in an agile manner, requiring additional coordination mechanisms between teams and also organizational units (Lindvall et al., 2004). While agile methods primarily focus on intra-team practices that work well in small organizations, agile methods do not provide sufficient guidance on how agile teams should

interact in large environments (Maples, 2009). Hence, large organizations must adapt the practices to their specific needs. As a result, practices may need to be put in place that require additional formal communication, which might reduce their agility (Lindvall et al., 2004). As often large organizations are globally distributed and agile methods are primarily based on frequent internal and external collaboration and communication (Highsmith and Cockburn, 2001), the use of agile practices in globally distributed projects can be challenging (Hanssen et al., 2011).

To address issues associated with adopting agile practices in large-scale organizations and projects, consultants and software practitioners have proposed several scaling agile frameworks, e.g., SAFe, LeSS, and DAD, which include predefined workflow patterns to deal with concerns related to large numbers of teams, inter-team coordination, and customer involvement (Alqudah and Razali, 2016; Dingsøyr et al., 2018b). As large organizations are increasingly pressured and expected to become more agile, and scaling frameworks claim to provide off-the-shelf solutions to scaling, companies have begun to adopt these frameworks at an increasing rate in recent years (Carroll and Conboy, 2019). This trend is also confirmed by the annual non-scientific survey on the State of Agile by Digital.ai (2020).

2.2.1. Definition of large-scale agile development

“When can a company be said to be adopting agile methods at scale rather than just at a smaller scale?” Several researchers have already tried to answer this question and have proposed several definitions on what *“large-scale agile development”* means. These definitions usually include the number of people or agile teams engaged in the effort or associated costs or duration of a project (Dingsøyr et al., 2014). Berger and Beynon-Davies (2009), for example, classify a project as a large-scale agile project if the project costs exceed 10 million GBP. Bjarnason et al. (2011a) use the project duration of more than two years as an indicator for classifying a project as large-scale. According to Paa-sivaara et al. (2008b), a project with more than 40 people or seven agile teams involved can be considered large-scale. To bring a conceptual clarity of what *“large-scale agile development”* means, Dingsøyr et al. (2014) have identified several different interpretations and proposed a taxonomy for large-scale agile development that uses the number of collaborating and coordinating teams to define the scale of an agile project. The taxonomy developed by Dingsøyr et al. (2014) consists of three categories: (i) small-scale agile projects with one team that can use traditional agile practices, e.g., daily meetings, sprint planning, review, and retrospective meetings, for intra-team coordination, (ii) large-scale agile projects with 2–9 agile teams that use new forums, e.g., a Scrum-of-Scrums (SoS) for cross-team coordination, and (iii) very large-scale agile projects with at least 10 agile teams that require several forums for inter-team coordination, e.g., multiple SoS. According to Dingsøyr et al. (2014), a project can be considered a large-scale project if it has at least two coordinating agile teams. Fuchs and Hess (2018) extend this definition and state that the term *“large-scale agile development”* has multiple interpretations: (i) the use of agile methods in large teams, (ii) the employment of agile methods in large organizations, (iii) the application of agile methods in large multi-team settings, i.e., *“large agile multi-team settings”*, or (iv) the usage of agile practices in organizations as a whole, i.e., *“organizational agility”*.²

² The term *“organizational agility”* should not be confused with the term *“enterprise agility”*, which constitutes a research direction for itself. According to our understanding, the term *“enterprise agility”* comprises the adoption of agile methods at the company level. In contrast, the term *“organizational agility”* insinuates the adoption of agile methods in large organizational units of companies, e.g., departments, divisions, or units. Hence, the term *“organizational agility”* can be seen as a subset of the term *“enterprise agility”*.

Like Fuchs and Hess (2018), we focus on the latter two definitions and understand the large-scale agile adoption of agile methods in large agile multi-team settings with at least two teams or the large-scale adoption of agile methods on the organizational level comprising multiple large agile multi-team settings.

2.3. Secondary studies on large-scale agile development

Several secondary studies have systematically analyzed the literature on specific topics related to large-scale agile development. We identified 13 secondary studies (see Table 1), of which 10 were systematic literature reviews, and three were either structured or simple literature reviews. Systematic literature reviews have addressed several topics, e.g., the identification and description of challenges (cf. Dikert et al., 2016; Uludağ et al., 2018b; Shameem et al., 2017), success factors (cf. Dikert et al., 2016; Shameem et al., 2017), and typical roles involved in large-scale agile endeavors (cf. Uludağ et al., 2017; Gustavsson, 2017). Various researchers also conducted systematic literature reviews and multi-vocal literature reviews on scaling frameworks to identify challenges, benefits, and success factors related to the adoption of scaling frameworks (cf. Putta et al., 2018; Kalenda et al., 2018; Edison et al., 2021). We also identified simple literature reviews comparing various scaling frameworks (cf. Alqudah and Razali, 2016; Ozkan and Tarhan, 2019).

Existing secondary studies cover and analyze specific research topics on large-scale agile development in-depth, e.g., large-scale agile transformations, scaling agile frameworks, or global and distributed software engineering. For instance, Dikert et al. (2016) deal with the research topic of large-scale agile transformations and explore the challenges and success factors reported for these transformations. For example, Edison et al. (2021) address the research topic of scaling agile frameworks by analyzing and comparing them based on their principles, practices, tools, and metrics, as well as identify gaps in the literature and proposing needs for future research. Shameem et al. (2017) deal with the research topic of global and distributed software engineering by identifying key success factors for scaling agile methods in these environments.

While existing studies focus on specific research topics in large-scale agile development and analyze them in-depth, we could not identify any systematic mapping studies that would provide an overview of the overall state of research in the field, structuring the body of knowledge in large-scale agile development. Hence, this paper aims to fill this gap by providing an overview of the research activities in large-scale agile development based on a systematic mapping study. As a systematic mapping study, the scope is broader than any existing systematic literature review, and the goals differ. While there is some overlap between this study and the systematic literature reviews of Dikert et al. (2016) and Edison et al. (2021), we provide a broader overview of the overall field of large-scale agile development than any single systematic literature review.

3. Research process

While systematic literature reviews (Kitchenham and Charters, 2007; Brereton et al., 2007) are a common means for identifying, evaluating, interpreting, and comparing all available research related to a particular research question, a systematic mapping study maps out the existing research rather than answering a detailed research question (Petersen et al., 2008; Budgen et al., 2008). Hence, we opted to conduct a systematic mapping study, as it is capable of dealing with broad research areas and provides a systematic and objective procedure for identifying, categorizing, and analyzing the existing literature (Petersen et al., 2008; Kitchenham and Charters, 2007; Budgen et al., 2008).

Table 1
Secondary studies on large-scale agile development

Year	Study	No. of studies	Topic
2014	Razavi and Ahmad (2014)	75	This study provides an understanding of research problems and themes in large-scale, distributed agile development environments based on IEEE publications between 2005 and 2014.
2015	Saeeda et al. (2015)	51	This paper identifies research issues related to the scalability of agile methods for large-scale projects. Moreover, this study unveils existing methods, approaches, frameworks, and practices that can facilitate the application of agile methods for large-scale agile projects, as well as their limitations.
2016	Dikert et al. (2016)	52	This article answers the question of how large organizations or projects adopt agile and/or lean methods at scale by focusing on the reported challenges and success factors encountered in large-scale agile transformations.
2017	Gustavsson (2017)	42	This work provides an analysis of roles assigned with the responsibility for inter-team coordination of large-scale agile development settings.
2017	Alsaqaf et al. (2017)	60	This paper presents challenges when developing quality requirements in large-scale distributed agile projects and reveals agile practices that have contributed to the emergence of these challenges. This work also summarizes solutions proposed in the literature to address challenges associated with developing quality requirements in large-scale distributed agile projects.
2017	Shameem et al. (2017)	20	This study presents key factors that can positively impact agile development activities in large-scale, globally distributed software development environments.
2017	Uludağ et al. (2017)	146	This paper gives an overview of 20 identified scaling agile frameworks and describes the responsibilities of different architects in these frameworks.
2018	Uludağ et al. (2018b)	76	This work presents different stakeholders and their recurring challenges in large-scale agile projects.
2018	Shameem et al. (2018b)	18	This article shows an overview of human-related factors that can negatively impact agile practices in large-scale, globally distributed software development environments and proposes a hypothetical model of the identified challenges related to the scaling of agile methods.
2018	Putta et al. (2018)	88	This study provides an analysis of the scientific and grey literature describing the challenges and benefits encountered by organizations when adopting SAFe.
2018	Kalenda et al. (2018)	12	This work examines practices, challenges, and success factors for scaling agile methods in large companies, reported in the literature and within a large software company.
2019	Abrar et al. (2019)	58	This paper shows a set of motivators for the large-scale adoption of agile methods from a management perspective.
2021	Edison et al. (2021)	191	This article compares five scaling methods based on each method's principles, practices, tools, and metrics. It also presents the challenges and success factors described in the literature when applying these methods.

3.1. Objectives and research questions

We used the Goal-Question-Metric paradigm ([Basili et al., 1994](#)) to formulate the objective of this study: to **analyze** peer-reviewed literature **for the purpose of** providing an overview of the state of the art **with respect to** the characterization of the topic, the available research on the topic, salient publications and researchers, well-established research streams, and potential research gaps **from the point of view of** scholars and practitioners **in the context of** large-scale agile development. The overall research question of this study is:

Research Question: What is the state of the art of the literature pertaining to large-scale agile development?

To answer this question, we further decomposed it into four specific questions:

RQ1: How is large-scale agile development characterized in the literature?

Currently, there is no consensus on the actual meaning of the term “large-scale agile development” ([Rolland et al., 2016](#)) which is why the lack of conceptual clarity regarding this term inhibits effective collaboration and progress in the research area of large-scale agile development ([Dingsøyr et al., 2014](#)). Thus, this research question strives to explore how the extant literature characterizes this term based on the reported case characteristics.

RQ2: What are the publication trends and characteristics of existing research on large-scale agile development?

A valuable instrument for understanding the nature of a research area is the investigation of research trends and the systematic classification of extant studies ([Petersen et al., 2008](#); [Budgen et al., 2008](#)). Accordingly, this research question intends to map the frequency of publications over time to identify research trends and strives to categorize and aggregate extant studies to structure the research area.

RQ3: What are the seminal studies in large-scale agile development?

There is perhaps no better way to understand and explore the intellectual structure of a research field than to identify its seminal works ([Dingsøyr et al., 2012](#); [Nerur et al., 2008](#)). Therefore, this research question aims to identify the protagonists and salient publications in the research field by employing bibliometric analysis.

RQ4: Which research streams and promising future research directions exist in large-scale agile development?

One approach to assess the state of the art and maturity level of a research area is to identify main research streams and reveal potential research gaps ([Petersen et al., 2008](#); [Kitchenham et al., 2011](#)). Hence, this research question strives to map the general structure of the research field by identifying central research themes. This research question also aims to outline a research agenda for future research efforts by analyzing existing gaps in the research streams.

3.2. Mapping study execution

When conducting this study, we followed the guidelines for performing systematic mapping studies ([Petersen et al., 2008](#)) and systematic literature reviews ([Kitchenham and Charters, 2007](#)). We decided to combine both approaches ([Kitchenham and Brereton, 2013](#)) since two of our research questions, namely RQ1 and RQ4, could not be answered by mappings alone. The execution procedure of this systematic mapping study consisted of three phases: (i) study search, (ii) study selection, (iii) and data extraction, as described in the following.

Table 2
Databases used in the main search.

#	Search engine	Website
DB1	IEEE Xplore	http://ieeexplore.ieee.org/
DB2	ACM Digital Library	http://dl.acm.org/
DB3	Science Direct	http://www.sciencedirect.com/
DB4	Web of Science	https://www.webofknowledge.com/
DB5	Scopus	https://www.scopus.com/home.uri
DB6	AIS eLibrary	https://aisel.aisnet.org/

3.2.1. Study search

In the first phase, we conducted a two-step study search procedure, which included the definition of a search strategy and the screening of related studies consisting of a preliminary search and main search, as described subsequently.

Study search strategy. Defining a proper search strategy is essential to ensure that the literature review results are complete (Zhang et al., 2011). Various researchers have proposed several techniques to develop appropriate search strategies (cf. Zhang et al., 2011; Petersen et al., 2015). We followed the recommendations by Zhang et al. (2011) to elaborate on our search strategy, which we describe in the following.

Search approach. Our search comprised two main steps: preliminary search and main search. The purpose of the preliminary search was two-fold. First, we wanted to use the preliminary search to construct and evaluate different search strings for the main search. Second, we used the preliminary search as a “sanity check” to identify a set of relevant papers that the actual main search should also retrieve. Following the preliminary search, we performed a database keyword search during the main search to retrieve relevant studies in electronic databases listed in Table 2. Afterward, we merged the search results from the preliminary and main searches and excluded duplicate studies. We then included the resulting collection of potentially relevant papers for the study selection phase.

Data sources. According to Brereton et al. (2007), many different electronic sources should be searched since no single source can find all relevant primary studies. Therefore, as suggested by Kitchenham and Brereton (2013), we selected six electronic databases (see Table 2) as the primary sources for the systematic mapping study for covering as many potentially relevant studies as possible. The selection of the electronic databases was guided by: (i) the fact that two of them, i.e., ACM Digital Library and IEEE Xplore, are the largest scientific databases in the field of software engineering (Petersen et al., 2015; Kitchenham and Brereton, 2013), (ii) the fact that three of them offer broad coverage of diverse research fields, i.e., Science Direct, Web of Science, and Scopus (Rodríguez et al., 2017), (iii) and the fact that one of them, i.e., AIS eLibrary, contains articles from the primary information systems research dissemination outlets (Oates, 2011). We excluded Google Scholar as the results tend to overlap with ones from the included electronic databases (Chen et al., 2010).

Search terms. To identify all relevant studies, we used a five-step strategy (Kitchenham et al., 2007) for constructing the search terms:

1. deriving main search terms from the study topic and the formulated research questions based on the PICO (Population, Intervention, Comparison, Outcomes) criteria,
2. identifying synonyms and alternative spellings for the main search terms,
3. checking the keywords in relevant papers,
4. incorporating synonyms and alternative words using the Boolean OR operator, and
5. linking the search terms using the Boolean AND operator.

Table 3
Overview of search sets and corresponding terms.

Set	Search term
Agile software development	((agile OR agility OR extreme programming OR XP OR feature driven development OR FDD OR scrum OR crystal OR pair programming OR test-driven development OR TDD OR leanness OR lean software development OR lean development OR LSD) AND NOT manufacturing)
Large-scale development	AND ((large-scale OR scaling)
Scaling agile frameworks	OR (Crystal Family OR Dynamic Systems Development Method Agile Project Framework for Scrum OR Scrum of Scrums OR Enterprise Scrum OR Agile Software Solution Framework OR Large-Scale Scrum OR Scaled Agile Framework OR Disciplined Agile OR Spotify Model OR Mega Framework OR Enterprise Agile Delivery and Agile Governance Practice OR Recipes for Agile Governance in the Enterprise OR Continuous Agile Framework OR Scrum at Scale OR Enterprise Transition Framework OR Scaled Agile Lean Development OR eXponential Simple Continuous Autonomous Learning Ecosystem OR Lean Enterprise Agile Framework OR Nexus OR FAST Agile))

We only used the first two components of the PICO approach, i.e., population and intervention, and omitted the outcome and context facets from the search structure since our research questions did not warrant a restriction of the results to a specific outcome or context. Similar to Yang et al. (2016), the population facet represents the first search set of the overall search string and contains the terms of agile methods that are popularly used in various systematic literature reviews and surveys on agile software development (cf. Dybå and Dingsøy, 2008; Rodríguez et al., 2012; Stavru, 2014). Following Dikert et al. (2016), we extended the first search set by explicitly stating that the application of agile methods outside of software engineering, e.g., agile manufacturing, should be excluded. The intervention comprises two search sets. The first set includes terms related to the objective of applying agile methods on a larger scale, namely “large-scale” and “scaling”. These two terms are often used within titles and as keywords in related publications on large-scale agile development (cf. Kalenda et al., 2018; Dingsøy et al., 2018b). Inspired by Yang et al. (2016), the second intervention search set entails terms of large-scale agile development methods and frameworks. We used the results of Uludağ et al. (2017) to obtain a list of these methods and frameworks. Following this strategy, we conducted a series of tests and refinements in the preliminary search. The blending of the search sets resulted in the generic search string for the main search. The final generic search string used was:

Agile software development AND (Large-scale development OR Scaling agile frameworks)

Table 3 lists the final list of applied search sets and strings. As each electronic database has a specific syntax for search terms, we adapted our search string to the particular syntax requirements of the search engines.

Time span. We cover the period from February 2001, when the Agile Manifesto was proposed, to the end of December 2019, when we started this systematic mapping study.

Preliminary and main search. Fig. 1 shows the study search process and the individual results obtained in each of both phases of the study search. In the preliminary search, we retrieved 693 studies. After removing duplicate studies, 631 papers were left. The main search returned 2090 publications. After removing duplicate papers, we ended up with 1643 papers from the main search. After merging the search results from the preliminary and

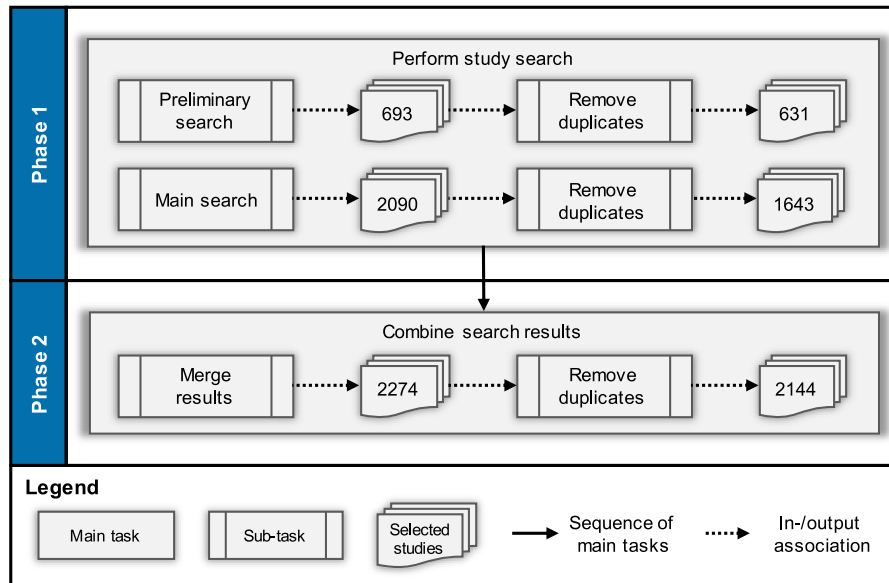


Fig. 1. Overview of the study search process.

main search and removing duplicates, we retrieved a total of 2144 articles that serve as input for the subsequent study selection process (see Section 3.2.2).

3.2.2. Study selection

After the study search process, we considered all 2144 studies for the subsequent study selection consisting of three screening phases: (i) selection of relevant articles based on their metadata (incl. title, keywords, publication year, and publication type), (ii) selection of relevant studies based on their abstract, and (iii) selection of relevant papers based on their full-text. The study selection was based on explicit inclusion and exclusion criteria and was conducted by two researchers in parallel. Following the individual decisions, the researchers harmonized their selection results and resolved conflicts. To ensure that the study selection results were objective, we created a set of well-defined inclusion and exclusion criteria employed in the selection process to filter relevant articles for our study.

Selection criteria. We defined selection criteria to reduce the likelihood of bias and to assess the relevance of the studies (Kitchenham and Charters, 2007). Before the study selection process, two researchers discussed and reached an understanding of the inclusion and exclusion criteria (see Table 4). We included an article if it satisfied *all* specified inclusion criteria and discarded it if it met *any* exclusion criterion. We only included peer-reviewed papers (see I3) that describe completed research results (see I4) and cover the large-scale application of agile methods (see I1 and I2), i.e., the application of agile methods in large multi-team settings or the usage of agile practices in organizations as a whole (see Section 2.2.1). Besides articles meeting any of the exclusion criteria (see E1–E7), we also excluded papers that did not indicate large-scale considerations or described the single team adoption of agile methods, not fulfilling I2.

Selection process. The selection process consisted of three phases (see Fig. 2). By the end of the third phase, the first researcher marked 269 studies as relevant, while the second researcher marked 145 studies as related. By the end of the fourth phase, 136 studies were characterized by both researchers as pertinent after resolving conflicts (inclusion rate of 6.34%).

Table 4

Inclusion and exclusion criteria.

ID	Criteria	Assessment criteria
I1	Inclusion	Describe the application of agile methods in software development.
I2	Inclusion	Cover the application of agile methods on a large scale and meet the requirements of being large-scale based on our understanding and definition of large-scale agile development in Section 2.2.
I3	Inclusion	Peer-reviewed, i.e., published in journals, conference or workshop proceedings.
I4	Inclusion	Papers that describe completed research results.
E1	Exclusion	Related to agile manufacturing.
E2	Exclusion	Published in the form of abstracts, book chapters, book and conference reviews, grey literature, magazines, newsletter, short communications, talks, technical reports, and tutorials.
E3	Exclusion	Articles that are not written in English language.
E4	Exclusion	Published before the creation of the Agile Manifesto.
E5	Exclusion	Not available as a full-text.
E6	Exclusion	Experience reports and opinion papers.
E7	Exclusion	Previous version(s) of extended papers.

3.2.3. Data extraction

To facilitate data extraction and simplify management of the extracted data, we adopted the approach of categorizing studies into facets (Petersen et al., 2008) and designed a rigorous classification framework based on these facets. Similar to study selection, we used a spreadsheet to record the extracted data. To reduce bias in the data extraction results, two researchers performed the data extraction independently. Before the formal data extraction process, two researchers discussed the definitions of the data items to be extracted to ensure that both researchers had a common understanding. After both scientists completed the data extraction, they discussed their results together and resolved conflicts to reach a consensus on the results. Fig. 3 shows the resulting classification framework, which consists of four facets and several subordinate data items.

Characterization of large-scale agile development (RQ1). To compile information about the characterization of large-scale agile

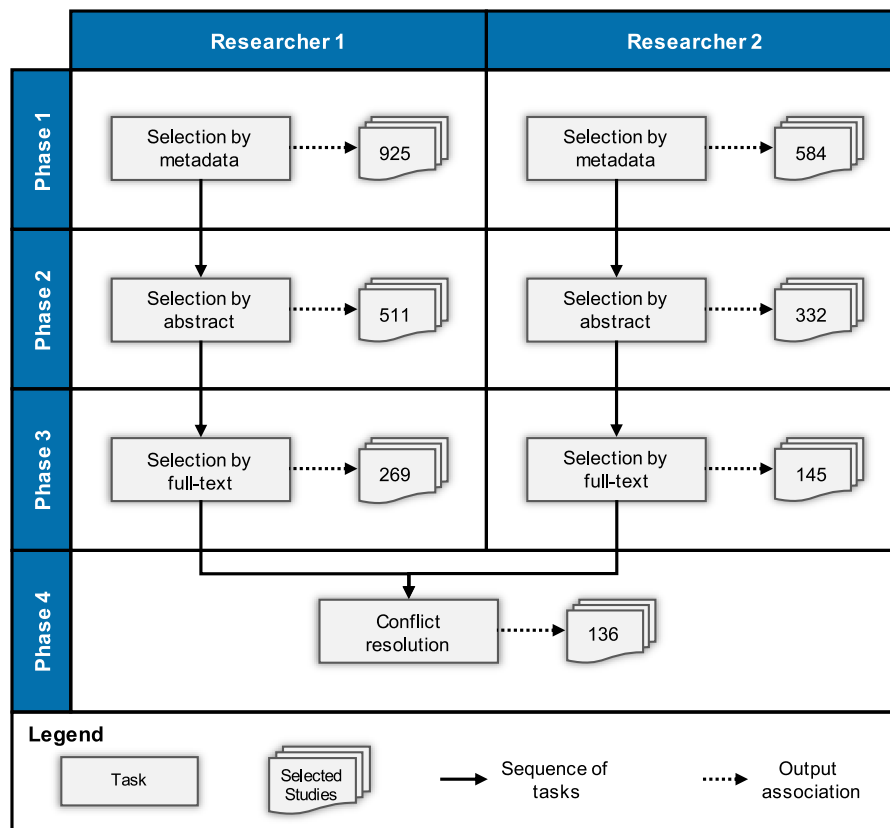


Fig. 2. Overview of the study selection process.

development, we collected information from the reported case characteristics regarding the four data items: *large-scale agile development category*, *case company characteristics*, *organizational agility characteristics*, and *large agile multi-team setting characteristics*. We extracted data for the *large-scale agile development category* data item to bring more conceptual clarity regarding the actual meaning of the term “large-scale agile development”. To this end, we used the classification by Fuchs and Hess (2018) to categorize the large-scale agile efforts of the reported companies. To get a better picture of companies adopting agile methods at scale, we divided the *case company characteristics* data item into four sub-data items, namely *company name*, *location of company headquarter*, *sector*, and *company size*. To obtain information on the four sub-data items, we combed through the case descriptions. In cases where the name of the company was provided but no other information about the company’s location, sector, or size was available, we used the information on the company’s website to complete the data. To classify the extracted data related to the *sector* sub-data item, we used the leading Global Industry Classification Standard³ from MSCI. We used the categorization of Digital.ai (2020) for classifying the reported case companies according to their *company size*. Using this categorization also helped us to compare our results more easily with those of Digital.ai (2020). To understand the trend of organizational agility and compile information related to the *organizational agility characteristics* data item, we read the case descriptions of the selected papers to determine the start date of the large-scale agile transformations of the reported case companies. To characterize the reported large agile multi-team settings, we split the *large agile multi-team setting characteristics* data item into three sub-data

items, namely *scaling and complexity factors*, *organizational size*, and *applied development and scaling approaches*. We used an integrated approach (Cruzes and Dybå, 2011) to extract data related to the *scaling and complexity factors* sub-data item. In doing so, we used the scaling and complexity factors reported by Ambler (2007) as a starting list and iteratively expanded it as we identified new factors. For the *organizational size* sub-data item, we read the case descriptions and looked for information on the number of agile teams and people involved in the agile multi-team settings. We used the taxonomy of Dingsøyr et al. (2014) to determine whether a setting was small-scale, large-scale, or very large-scale. To extract data related to the *applied development and scaling approaches* sub-data item, we applied an integrated approach (Cruzes and Dybå, 2011) and used the lists of Abrahamsson et al. (2017) and Uludağ et al. (2017) for agile development and scaling approaches and refined the initial lists as new approaches were identified in the studies.

Publication trends and research characteristics (RQ2). Fig. 3 shows the data items we used to collect data about publication trends and research characteristics. The *publication year*, *country of authorship*, and *publication venue* were retrieved directly from the studies’ metadata. Based on the *publication venue*, we derived the *publication type* with a classification scheme consisting of the three categories: *journal*, *conference*, and *workshop*. To classify the *publication domain*, we read the website information of the publication venues and categorized them into one of eight primary publication domains: *enterprise computing*, *information systems*, *IT project management*, *human computer interaction*, *marketing*, *multidisciplinary*, *project management*, and *software engineering*. To classify the research types, we adopted a framework consisting of six categories based on Wieringa et al. (2006) (see Table 5). For the *research approach* data item, we used a combination of three taxonomies and definitions of Berg et al. (2018), Rodríguez

³ <https://www.msci.com/our-solutions/indexes/gics>, last accessed on: 11-13-2021.

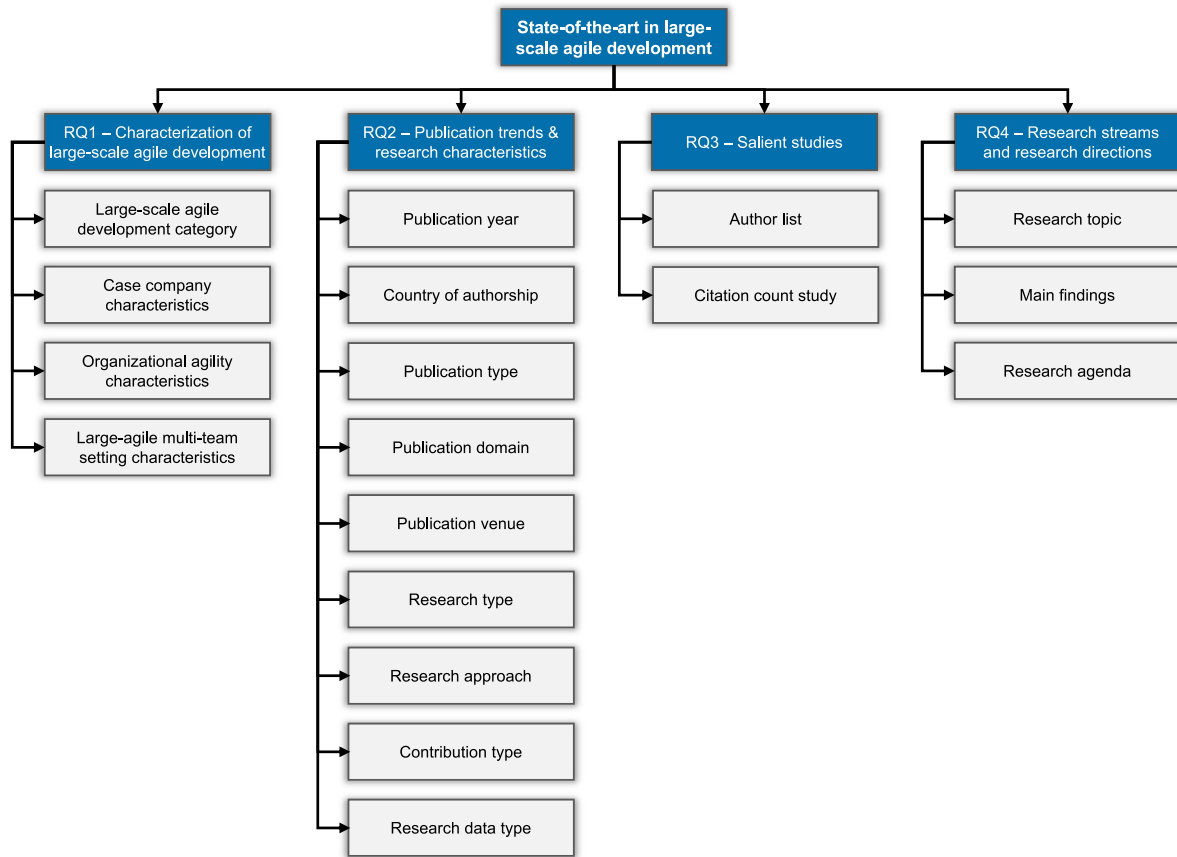


Fig. 3. Classification framework.

Table 5

Classification scheme for research types based on Wieringa et al. (2006).

Research type	Description
Evaluation research	The implementation of existing techniques and solutions are evaluated in practice.
Experience reports	Practitioners report their own experiences from one or more real-life projects without discussing the article's underlying research method.
Opinion papers	Express the author's personal experience regarding a technique's suitability without relying on related work and research methods.
Philosophical papers	These articles sketch a new perspective on looking at existing things by structuring the field using a taxonomy or conceptual framework.
Solution proposal	A new or significant extension of an existing technique is shown by demonstrating its benefits and applicability.
Validation research	Focus on the investigation of novel techniques that have not yet been implemented in practice.

et al. (2017), and Unterkalmsteiner et al. (2011) to have a complete list of research methods consisting of nine categories (see Table 6). For the *contribution type* data item, we used two existing taxonomies of Shaw (2003) and Paternoster et al. (2014) to have a complete list of research outcomes consisting of seven categories (see Table 7). The *research data type* consists of three categories indicating whether a study is *primary*, *secondary*, or *tertiary*.

Seminal studies (RQ2). To compile information about influential studies, we used two data items: *author list* and *citation count study*. We obtained the *author list* from the metadata of the

Table 6

Classification scheme for research approaches based on Berg et al. (2018), Rodríguez et al. (2017), and Unterkalmsteiner et al. (2011).

Research approach	Description
Action research	Applies action research to solve a real-world problem while simultaneously scrutinizing the experience of solving the problem.
Case study	Uses a case study to provide an in-depth understanding of a real-life situation and contemporary phenomenon or evaluates a theoretical concept by empirically implementing it in a case study.
Design and creation	Creates a new IT product, artifact, model, or method.
Grounded theory	Uses a systematic process to generate theory from the data obtained based on grounded theory.
Mixed methods	Applies more than one research methodology.
Systematic literature review/Systematic mapping study	Collects and analyzes primary data to address a specific research question or topic using a systematic literature review or systematic mapping study.
Survey	Collects quantitative and/or qualitative data in a standardized, systematic way to find patterns through a questionnaire or interviews.
Theoretical	A theoretical study not mentioning grounded theory as the research methodology.
Not stated	Does not state the research method, nor can it be derived or interpreted by reading the paper.

selected papers. We collected data for the *citation count study* data item via Google Scholar.

Research streams and research directions (RQ4). To identify central research themes and future research directions, we collected

Table 7

Classification scheme for contribution types based on Shaw (2003) and Paternoster et al. (2014).

Contribution type	Description
Advice/Implication	Discursive and general recommendation based on personal opinions.
Framework/Method	Framework or method to facilitate the construction and management of software-intensive systems.
Guideline	List of advice or recommendations based on the synthesis of the research results obtained.
Lessons learned	Set of outcomes which are analyzed from the research results obtained.
Model	Representation of an observed reality using concepts resulting from a conceptualization process.
Theory	Construct of cause-effect relationships from determined results.
Tool	Technology, program, or application developed to support various aspects of software engineering.

data on research topics and agendas in the selected papers. We followed a systematic process called *keywording* (Petersen et al., 2008) to define the categories of the *research topic* facet. The purpose of the keywording process is to effectively develop a classification framework that fits the selected studies and takes their research focus into account (Petersen et al., 2008). The keywording process consists of the following three steps:

1. *Identifying keywords and concepts*: Two researchers collected keywords and concepts by reading the full-text of each starting study.
2. *Clustering keywords and concepts*: Two researchers performed a clustering operation on the collected keywords and concepts into a set of categories and sub-categories.
3. *Refining classification*: Four researchers discussed the preliminary categories and sub-categories. This discussion resulted in the refinement of the classifications to fit them better with the selected studies.

The above-described process ended when no study was left to analyze. During the extraction process, some studies could be classified into more than one research topic. We read the results, discussion, and conclusion sections of the studies to identify their *main findings* and mapped them to the main research topic categories. We used a deductive approach (Cruzes and Dybå, 2011) to categorize the *research agenda* of the selected studies based on the final classification of the *research topic* facet. Two researchers read the selected studies' future work sections and mapped the corresponding text fragments to the identified main research topic categories. In addition to the selected studies, we read and mapped relevant data from nine related workshop summaries. They provide a list of important future research topics proposed by researchers and practitioners familiar with large-scale agile development. Following the coding procedure, two researchers merged and aggregated related codes and reformulated the final codes as research questions.

4. Study results

In this section, we provide a review of the state of the art of large-scale agile development research and present our answers to the formulated research questions (see Section 3.1). This section is arranged according to the research questions.

Table 8

Overview of the identified case companies.

Company	No. of studies
Anonymous	67
Ericsson	23
Norwegian Public Service Pension Fund	8
F-Secure	2
Nokia	2
ABB	1
Apontador	1
BBC	1
Caelum	1
Cisco	1
Comptel	1
Dell	1
Information Mosaic	1
Intel	1
Kentico	1
Paf.com	1
Rovsing	1
SAP	1
SimCorp	1
Spotify	1
ThoughtWorks	1
Universo Online	1

4.1. Characterization of large-scale agile development

Although we discussed the term “large-scale agile development” in Section 2.2.1 and stated our understanding of it, we were curious to learn what other authors refer to as large-scale agile development. In what follows, we provide an overview of case companies we studied and identify which category of large-scale agile development, i.e., large agile multi-team settings or organizational agility, was reported. We then highlight our key findings for each category.

4.1.1. General overview of the case companies

We identified 158 case companies, of which 137 remained unnamed in 67 studies.⁴ A total of 21 companies were explicitly named in 41 studies. Table 8 shows an overview of the identified companies and the number of studies reporting them. The most frequently identified company was Ericsson (cf. Petersen and Wohlin, 2009, Paasivaara and Lassenius, 2014, Evbota et al., 2016), followed by the Norwegian Public Service Pension Fund (cf. Dingsøyr et al., 2018c, Dingsøyr et al., 2017, Dingsøyr et al., 2018b). Other companies repeatedly studied were F-Secure (cf. Heikkilä et al., 2010, Heikkilä et al., 2015b) and Nokia (cf. Laanti et al., 2011, Paasivaara and Lassenius, 2016). The remaining 17 companies were mentioned only in one study. As a result, we notice that research on large-scale agile development is mainly empirical and practice-oriented, as almost 80% of the studies examine companies in their respective analyses. We note that a significant portion of the research was conducted with Ericsson, accounting for nearly 17% of all selected studies. We notice that many studies provide superficial case descriptions, making it difficult to generalize and compare results.

Fig. 4 shows the countries where the headquarters of reported companies are located, with circles indicating the number of companies in a given country. We identified the geographic location of 58 companies. Although most companies are located in Europe, large-scale agile development is a relevant practical topic on all continents. Most companies come from Germany, followed by the United States, Norway, and Sweden. Like the State of Agile survey (Digital.ai, 2020), we note a concentration

⁴ There is some likelihood that some unnamed companies are duplicates. Many case descriptions were too superficial to allow clear identification.



Fig. 4. Geographical distribution of the case companies.

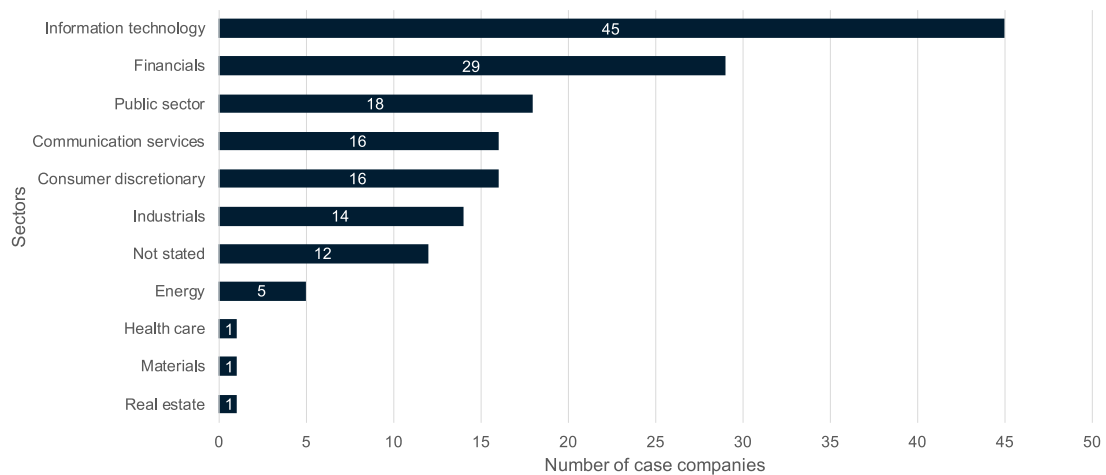


Fig. 5. Distribution of the case companies according to their sectors.

of industry relevance of the topic in Europe and North America. Based on our selection criteria (see Section 3.2.2), we identified fewer companies from North America compared to the State of Agile survey (Digital.ai, 2020) as we excluded many experience reports and opinion articles from North America.

Fig. 5 shows the distribution of the companies across their sectors. While 146 companies come from 10 different sectors, we could not identify the respective sectors for 12 companies. Almost a third of all reported companies come from the information technology sector, followed by the financial and public sectors. Our findings align with the State of Agile survey (Digital.ai, 2020) stating that a large proportion of the companies using (large-scale) agile methods come from the information technology and financial sectors. Notably, 44% of the companies surveyed come from

the information technology and finance sectors, while 46.84% of our companies are from these sectors.

Fig. 6 shows the distribution of the reported companies over their sizes. While we were able to determine the organizational size of 89 companies, we could not reveal the size of 69 companies. Most companies employ >20,000 employees, followed by companies with ≤1000 employees. Comparing our results to those of the State of Agile survey (Digital.ai, 2020), we can see some similarities and differences. Like the survey (Digital.ai, 2020), the majority of reported companies are small (≤1000 employees) or very large (>20,000 employees). While these two groups account for 66% of survey respondents, they account for 65.17% of the reported companies in this study. The majority of the companies in our sample are very large, followed by small

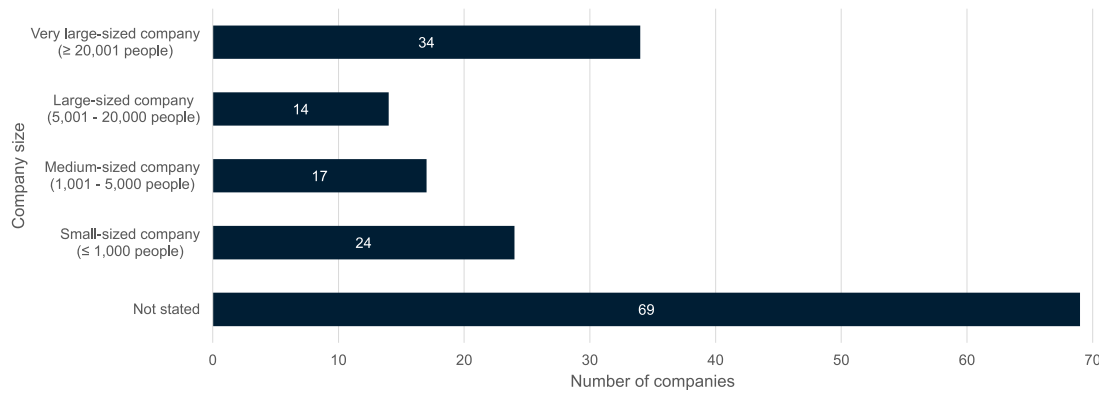


Fig. 6. Distribution of the case companies according to their sizes.

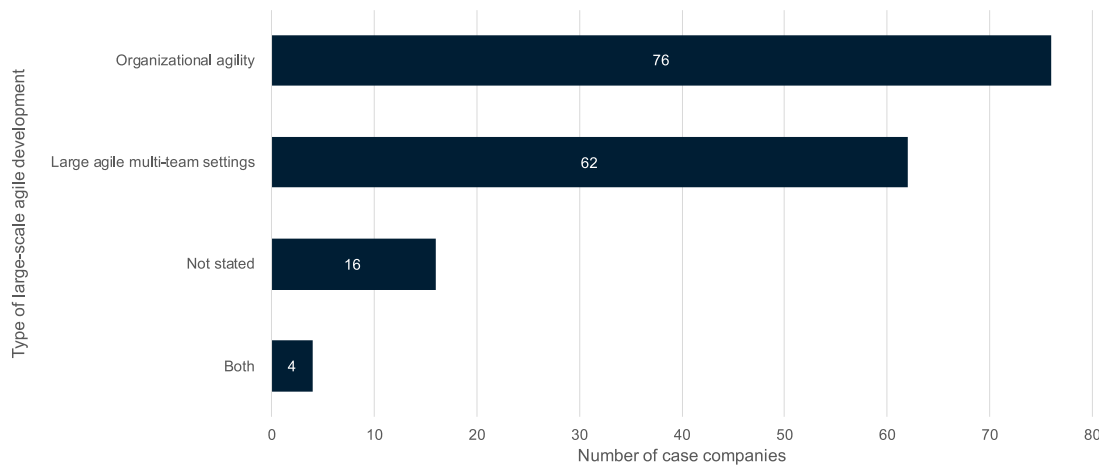


Fig. 7. Type of reported large-scale agile development.

companies, which is precisely the opposite of the survey (Digital.ai, 2020). One reason for this could be that the survey (Digital.ai, 2020) covers both the small- and large-scale adoption of agile methods. Our research exclusively considers the large-scale application of agile practices, which may be more relevant for large companies than for small companies with fewer scaling issues.

4.1.2. Understanding of large-scale agile development

Since there are several definitions of large-scale agile development in the literature (see Section 2.2.1) and there is no consensus on the actual meaning of the term (Rolland et al., 2016; Dingsøyr et al., 2014), we were curious what is meant by “large-scale agile development” in the literature. To this end, we used the classification by Fuchs and Hess (2018), i.e., the adoption of agile methods in large multi-team settings (“large agile multi-team settings”) with at least two agile teams working on a single product or the usage of agile practices in organizations as a whole (“organizational agility”), to analyze the large-scale agile efforts of the reported companies. Fig. 7 shows the categories that have been reported. Nearly half of all companies applied agile practices in organizations as a whole, while 39.24% of all companies used agile methods in large multi-team settings. An example for organizational agility is provided by Fuchs and Hess (2018) who conceptualize the agile transformation process through the lens of socio-technical systems theory by analyzing the large-scale agile transformations of two companies from the financial and consumer discretionary sectors. An example for large agile multi-team settings is shown by Šablís and Šmite (2016) who study inter-team coordination mechanisms of a large-scale agile

development program of the Norwegian Public Service Pension Fund with eight teams. In four companies, both categories were reported. For instance, Power (Power, 2014) explains the notion of “agile at scale” by showing an example of Cisco using agile practices in the whole organization and having multiple development efforts with several agile teams working together. For 16 companies (cf. Martini et al., 2015; Nyfjord et al., 2014), we did not determine the category due to superficial context information.

In the following, we delve into the selected studies and provide more in-depth information in light of both categories of large-scale agile development reported in the companies.

4.1.3. Organizational agility

To understand the trend of organizational agility, we analyzed when the case companies started their large-scale agile transformations. Fig. 8 shows the distribution of when case companies started their large-scale agile transformations. We derived information on the agile transformations of 20 case companies. The first two observed transformations towards organizational agility began in 2006 at F-Secure (cf. Heikkilä et al., 2015b) and Paf.com (earlier Eget) (cf. Rautiainen et al., 2011), when the company-wide adoptions of Scrum were initiated. While nine transformations started between 2006 and 2012, 11 transformations began between 2014 and 2017, indicating a growing number of transformations in recent years. Comparing these numbers with the number of studies published (see Section 4.2.1), we perceive the congruent interest from industry and academia in the topic.

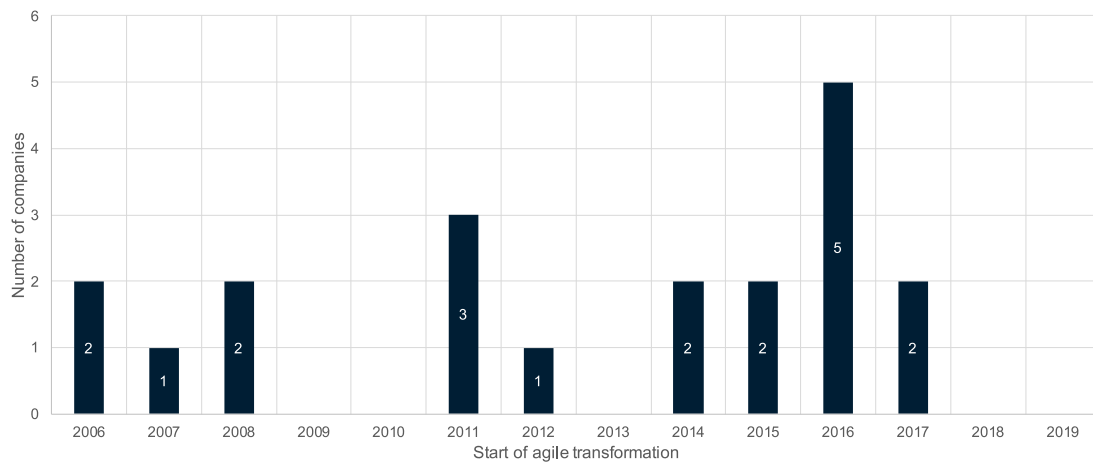


Fig. 8. Start of the agile transformations of the case companies.

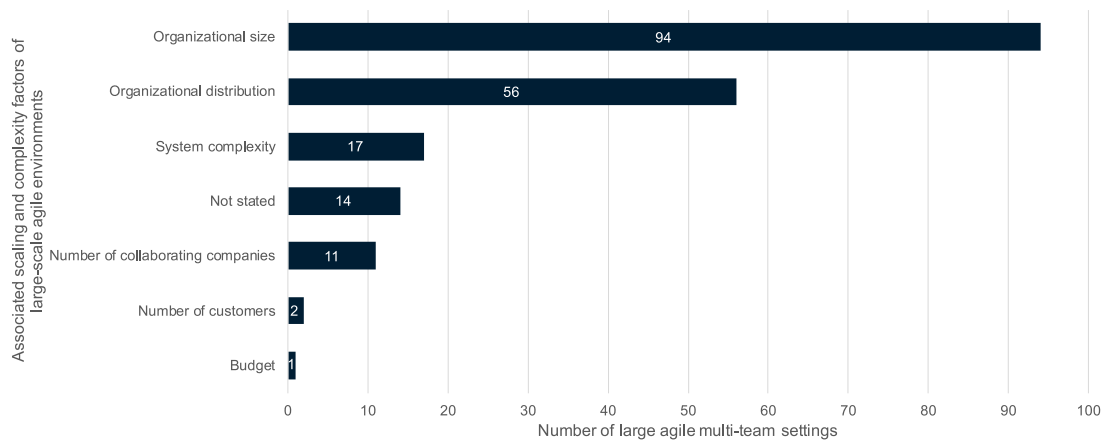


Fig. 9. Scaling and complexity factors of large-scale agile environments.

4.1.4. Large agile multi-team settings

We identified 110 agile development efforts⁵ with multiple teams. There were also some companies with more than one effort. For instance, we uncovered 11 efforts with 6–40 agile teams at Ericsson, reported in 20 studies (cf. Petersen and Wohlin, 2009, Paasivaara and Lassenius, 2014, Evbota et al., 2016). Another example is provided by Bick et al. (2016), who describe the inter-team coordination of five large agile multi-team settings at SAP, involving 4–13 teams.

Based on our ambition to gain a deeper understanding of what the authors of the selected studies mean by the “*scaling of agile methods*”, we examined the case descriptions in terms of possible scaling and complexity factors of large agile multi-team settings. Fig. 9 provides an overview of the identified factors. We identified six scaling and complexity factors associated with large agile multi-team settings, i.e., organizational size, organizational distribution, product size, number of collaborating companies, number of customers, and budget. Organizational size, i.e., the number of agile teams working together or the number of people in the development effort, was the most frequently observed factor. For instance, Paasivaara and Lassenius (2016) present a case study of scaling Scrum in a large globally distributed software project at Nokia. The study expresses the scale and complexity

of the case project by describing that it scaled from two collocated Scrum teams to 20 teams, i.e., the number of agile teams working together, and now employs 170 people, i.e., the number of involved persons in the development effort. Organizational distribution of large agile multi-team settings was the second most frequently identified factor. Here, the studies specify the number of sites a development effort has and provide information regarding the geographic distribution of the development effort. For example, Usman et al. (2018) examine how a large-scale distributed agile project at Ericsson performs effort estimation. The study further delineates the project’s organizational distribution by stating that the project is distributed across Sweden, India, Italy, the United States, Poland, and Turkey. The third most frequently cited factor is related to the complexity of the developed system, i.e., product size (measured in lines of code), number of subsystems, and number of requirements and features. For instance, Moe et al. (2014) investigate the intra- and inter-team knowledge sharing in a large-scale distributed agile project at Ericsson, developing a product with 10–12 million lines of code and 30 subsystems. In the case of 14 large agile multi-team settings, the studies did not provide information on scaling and complexity factors. For instance, a multiple case study of five software-intensive companies by Olsson and Bosch (2015) reveals challenges associated with collecting and using customer feedback. Although we can infer from the context of the study that it analyzes large agile multi-team settings of five companies, we did not find further descriptions of their characteristics. Moreover, the number of companies working together was an additional factor. For example, Uludağ et al. (2019c) investigate the

⁵ There is some likelihood that some large-scale agile development efforts are duplicates, e.g., same settings at different times. Some case descriptions were too superficial to allow unambiguous identification.

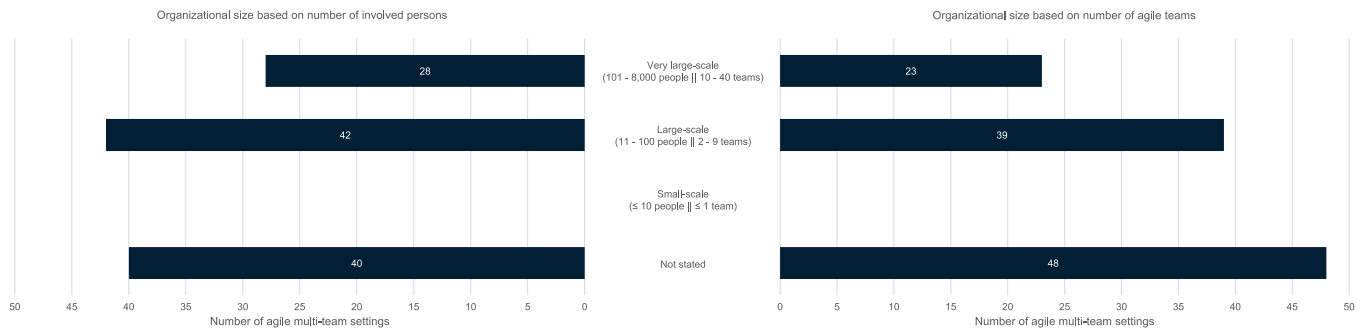


Fig. 10. Distribution of organizational sizes of the large agile multi-team settings in terms of number of involved persons and agile teams.

collaboration between architects and agile teams of a large-scale agile development program at a German consumer electronics company. The reported large-scale agile program includes 62 persons employed in four companies, i.e., consumer electronics and three suppliers providing external support for their third-party systems. In two large agile multi-team settings, the number of customers/users of the developed software product was cited as a factor. For example, a large-scale agile program at Ericsson creates a complex system used by over 300 operators around the world (cf. Paasivaara and Lassenius, 2014, Paasivaara and Lassenius, 2019, Paasivaara et al., 2013). For instance, a large-scale agile endeavor implements a new office automation system for the Norwegian Public Service Pension Fund serving 950,000 customers with various types of services (cf. Paasivaara et al., 2012a, Bjørnson et al., 2018). Budget was reported in one setting, namely at the Norwegian Public Service Pension Fund, which is one of the most extensive IT programs in Norway with a budget of about 140 million EUR (cf. Dingsøyr et al., 2018c, Dingsøyr et al., 2017, Dingsøyr et al., 2018b). Comparing our findings with the scaling and complexity factors of Ambler (2007), we note some similarities and differences. Like Ambler (2007), we believe that organizational size is the primary scaling and complexity factor for characterizing the term “scaling of agile methods”. Like Ambler (2007), we believe that other important factors are organizational distribution and system complexity. Unlike Ambler (2007), we identified the number of collaborating companies, the number of customers, and the available budget for development efforts as additional scaling and complexity factors.

Since organizational size was the main reported factor, we were curious to analyze the sizes of the agile multi-team settings. Fig. 10 shows the distribution of the number of people and teams involved in the agile multi-team settings. Of the 110 reported agile multi-team settings, we determined the number of people involved for 70 settings and the number of teams for 62 settings. We could not determine the number of people engaged for 40 settings and the number of teams for 48 settings. Most of the reported agile multi-team settings were large and included 11–100 people or 2–9 teams, followed by very large settings that involved 101–8000 people or 10–40 teams. Based on our understanding of large-scale agile development (see Section 2.2.1) and excluding projects with <2 teams, we found no small-scale projects. Our results show some notable differences from the State of Agile survey (Digital.ai, 2020). While 70% of the settings (excluding settings without numbers) had ≤100 employees, 33% of all survey respondents reported that their software organizations had <100 employees. While 36% of the survey respondents indicated software organization sizes with 101–1000 employees, this was the case for 46.67% of agile multi-team settings in this study. A significant difference between this study and the survey is observed for software organization sizes with >1001 employees. While 31% of the survey respondents reported software organization sizes

of >1001 people, we identified only one very large agile multi-team setting at Cisco with 8000 employees (cf. Power, 2014). This discrepancy may be due to our selection criteria related to experience reports and opinion papers (see Section 3.2.2) led to the exclusion of companies in North America with likely larger sizes.

Finally, we were interested in exploring the applied development and scaling approaches reported in the large agile multi-team settings, visualized in Fig. 11. SoS is the most commonly used scaling approach reported, followed by SAFe and LeSS. The Spotify Model was described in three settings, followed by DAD in one setting. Comparing our numbers with those from the State of Agile survey, we see some similarities and differences. While the survey showed SAFe as the most commonly used scaling approach among respondents (35% of their respondents), only 8.18% of the large agile multi-team settings reported using SAFe. For SoS, the numbers are similar as 18.18% of all settings used this scaling approach, while 16% of the survey participants applied it. In addition, 4% of the survey participants reported using LeSS, while 7.27% of the settings in this study used LeSS. While we identified the adoption of DAD in only one setting, 4% of all survey participants adopted it. Scrum was the most frequently cited development approach, followed by Kanban and XP. Re-comparing our results with the survey data confirms that Scrum is by far the most frequently used development approach, i.e., 58% of the survey respondents mentioned Scrum. In contrast, Scrum was used in 72.7% of all large agile multi-team settings reported in this study. While 10.91% of the settings reported using Kanban, that number accounted for 7% of all survey respondents. About half of the settings stated the combined usage of development and scaling approaches. For instance, a large multi-team project at F-Secure, which included >10 teams and >140 stakeholders, used a combination of Scrum, SoS, and an early version of SAFe (cf. Heikkilä et al., 2010, Heikkilä et al., 2015b). Uludağ et al. (2018a), for example, describe a unit with three agile teams who worked with other groups to develop an integrated sales platform for multiple sale distribution channels, using LeSS extended with some XP practices.

4.2. Publication trends and characteristics of existing research on large-scale agile development

To map publication trends and characteristics of extant research on large-scale agile development, we chose a set of variables focusing on each study's publication and bibliographic data. Below, we detail the key facts drawn from our analysis.

4.2.1. Distribution of studies over time

Fig. 12 presents the distribution and cumulative sum of selected studies, providing a clear message on an apparent increasing trend in publications on large-scale agile development.

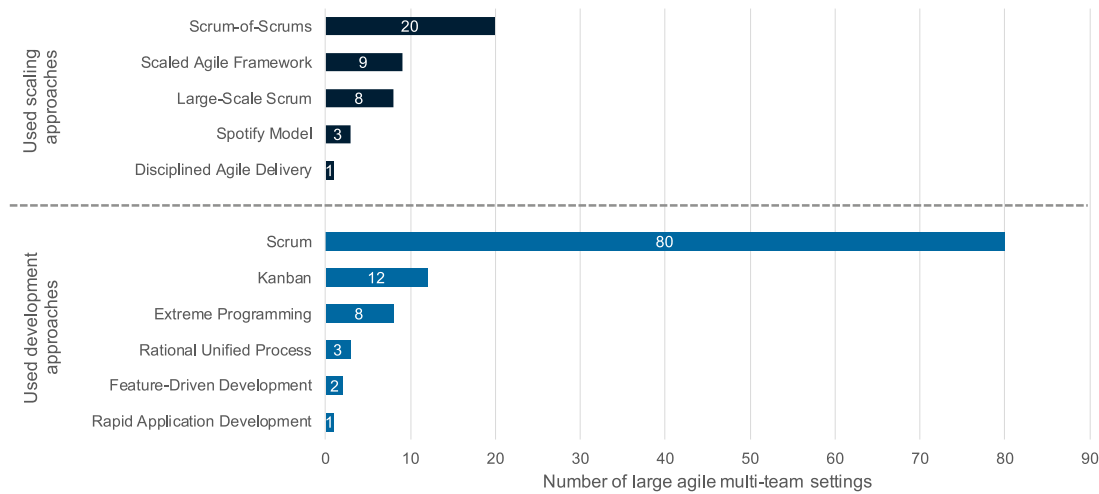


Fig. 11. Applied development and scaling approaches in the large agile multi-team settings.

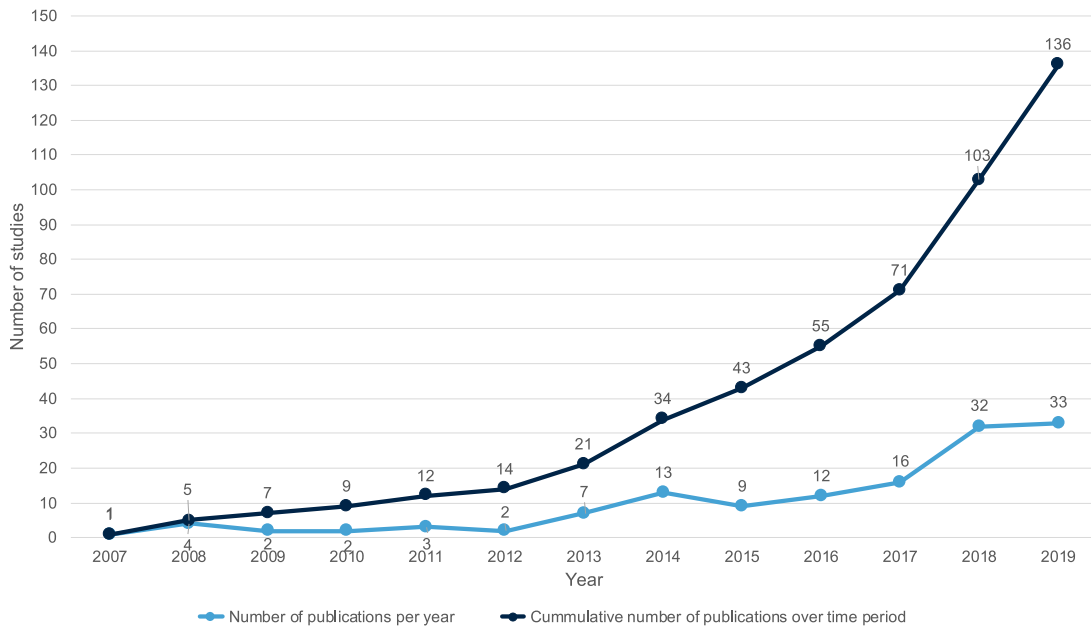


Fig. 12. Publications on large-scale agile development from 2007 to 2019.

In general, the number of selected studies on this topic has increased from 2007 to 2019, with slight fluctuation. This trend indicates that the large-scale application of agile methods is receiving increasing attention from the research community. Except for 2007, at least two studies were published during the observation period. From 2013 onwards, a growing trend can be observed with at least seven studies published per year, which is a giant leap compared to the years before 2013. Two reasons for this could be that the agile software development community initiated an increasing paradigm shift towards the adoption of agile methods in large projects in 2013 (Dingsøyr and Moe, 2013; Freudenberg and Sharp, 2010) and that the International Workshop on Large-Scale Agile Development was held for the first time in 2013. After 2013, 84.55% of the selected studies were published in the last six years, indicating that the topic of large-scale agile development is relatively infancy when compared to the history of the software engineering discipline and is becoming increasingly attractive from a scientific perspective. The growing trend towards the topic culminated in 2018 and 2019 when the number of publications doubled compared to previous years, accounting for a total of 47.79% of the selected studies. One possible

explanation for this is that additional workshops contributing to large-scale agile development research were initiated, e.g., the International Workshop on Autonomous Agile Teams in 2018 and the International Workshop on Agile Transformation in 2019. Based on these observations, we expect this trend to continue.

4.2.2. Most active countries in large-scale agile development research

Fig. 13 shows the countries that are most active in large-scale agile development research. We identified 22 states contributing to large-scale agile development research. The majority of the articles are from Europe, accounting for 88.97% of all publications. The research theme of large-scale agile development received considerable interest in Scandinavia, with 74 papers. Accordingly, the most active countries in this research area are Finland, Norway, and Sweden. The fourth and fifth most active countries are Germany and the United Kingdom. The remaining 17 states have fewer than 10 publications and contributed only 32 articles. From the available data, we conclude that large-scale agile development is a globally relevant research topic. Although Dingsøyr et al. (2012) revealed that the United States and



Fig. 13. Map of most active countries in large-scale agile development research.

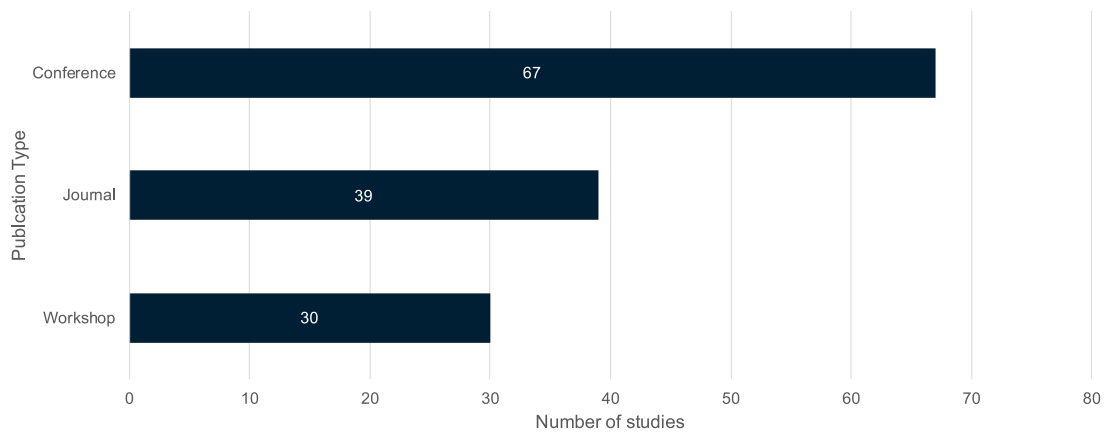


Fig. 14. Distribution of publication types.

Canada contributed to research on agile software development with 448 out of 1551 selected studies, we identified only three studies on large-scale agile development. A plausible explanation for this phenomenon is that we identified numerous experience reports and opinion papers from both countries that were excluded by our selection criteria (see Section 3.2.2) (cf. [Hodgkins and Hohmann \(2007\)](#), [Koehnemann and Coats \(2009\)](#) and [Rajpal \(2016\)](#)). Comparing the map of most active countries in large-scale agile development research (see [Fig. 13](#)) with the geographic location of the reported companies (see [Fig. 4](#)), a considerable overlap can be observed. A logical reason for this observation is that researchers tend to work with companies that are located in closer proximity.

4.2.3. Publication channels

To examine the pertinent publication channels for large-scale agile development research, we collected data on publication

types, venues, and domains for each selected study. [Fig. 14](#) shows the proportion of publication types for the 136 selected studies. The predominant publication type is that of conference papers, being almost as much as the combination of journal articles and workshop papers. Such a high number of journal and conference papers may indicate that large-scale agile development is becoming a more mature research area despite its relatively young age. The relatively small number of workshop papers suggests that researchers prefer more scientifically rewarding publication types, e.g., journals and conferences.

[Fig. 15](#) shows an annual distribution of the publication type facet. After 2013, an increasing trend can be observed for all publication types, culminating in 2018 and 2019. This observation may further confirm that large-scale agile development is turning into a more mature field, with more fundamental and comprehensive studies published in recent years. Although journals were the predominant publication type between 2007 and

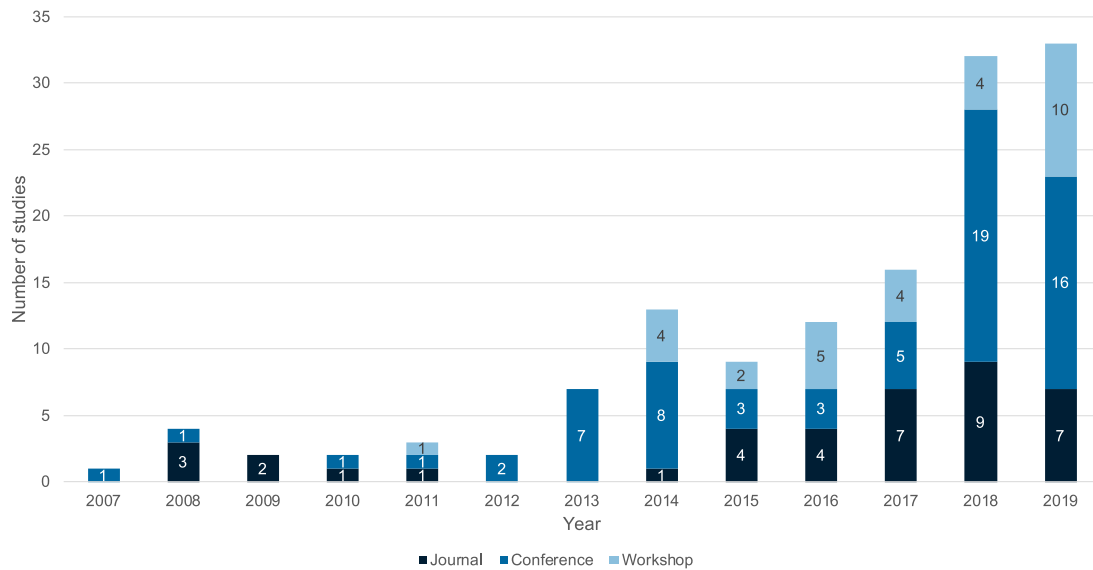


Fig. 15. Distribution of publication types over time.

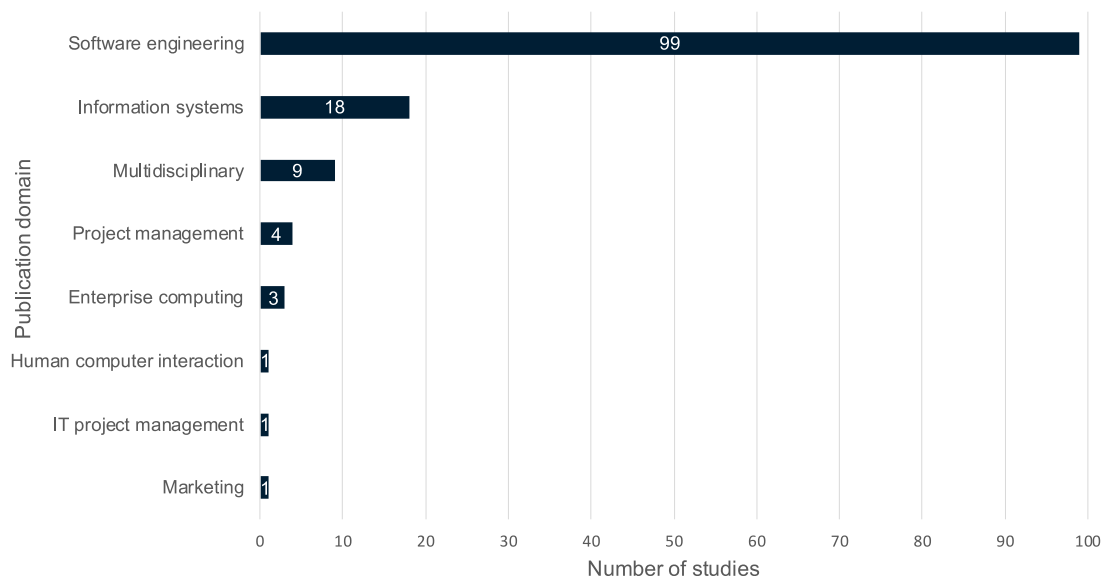


Fig. 16. Distribution of publication domains.

2011, we can observe that conferences and workshops became increasingly prevalent from 2012 onwards, as more venues on the topic were initiated or existing venues included large-scale agile development in their research program.

Fig. 16 presents the distribution of selected studies across publication domains. We identified eight publication domains that cover research related to large-scale agile development. Unsurprisingly, most of the publications are covered by publication venues from the software engineering research domain, followed by the information system and project management research areas. Nine articles were published in venues covering various research topics, e.g., IEEE Access embracing all IEEE fields of interest or *Procedia Computer Science* containing conference proceedings on all computer science topics. Although most of the studies stem from the software engineering field, we recognize a growing interest in large-scale agile development research from further research communities, e.g., information systems, project management, and enterprise computing.

To corroborate this observation, we show in Fig. 17 how the number of publications has evolved across the identified publication domains. Large-scale agile development is primarily and expectedly domicile in the software engineering field, with at least one published study per year and a peak in 2019 with 22 publications. Research on large-scale agile development has also aroused an early interest in publication venues related to information systems. After 2013, we observe a growing interest in the topic outside of software engineering. While only two articles were published in venues unrelated to software engineering between 2007 and 2012, further 35 articles were published between 2014 and 2019, representing 94.59% of all studies outside of software engineering. These numbers are coherent with our observations. We notice a general interest in the topic in various academic fields in recent years, as the large-scale adoption of agile methods has far-reaching implications for companies, which in turn is very interesting for many scientists to investigate from an empirical point of view.

A look at the specific targeted publications venues shows that research on large-scale agile development is published in

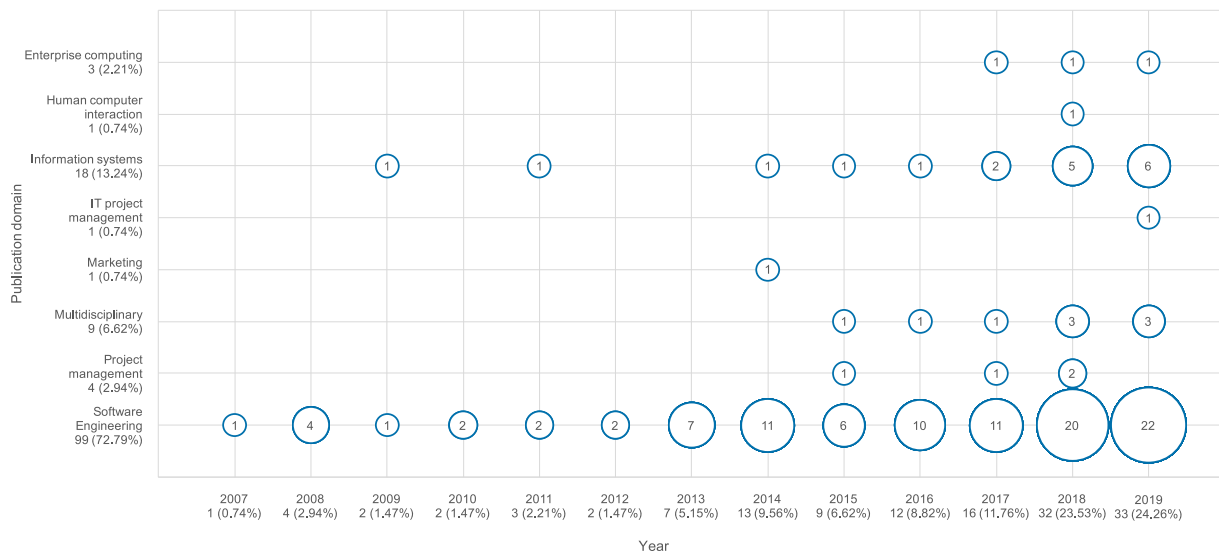


Fig. 17. Number of studies per publication domain over time.

Table 9

Top-10 publication venues ranked by number of submitted studies.

#	Publication source	Type	Domain	No.	%
1	International Conference on Agile Software Development	Conference	Software engineering	21	15.44
2	International Workshop on Large-Scale Agile Development	Workshop	Software engineering	20	14.71
3	International Conference on Global Software Engineering	Conference	Software engineering	9	6.62
4	IEEE Software	Journal	Software engineering	6	4.41
5	Information and Software Technology	Journal	Software engineering	6	4.41
6	International Workshop on Autonomous Teams	Workshop	Software engineering	6	4.41
7	Empirical Software Engineering	Journal	Software engineering	5	3.68
8	Hawaii International Conference on System Sciences	Conference	Information systems	5	3.68
9	Americas Conference on Information Systems	Conference	Information systems	4	2.94
10	Journal of Systems and Software	Journal	Software engineering	4	2.94

various venues. The 136 selected studies are distributed across 46 publication venues (see Appendix A), including 17 journals, 23 conferences, and six workshops, indicating that research on large-scale agile development is receiving wide attention in the research community. Table 9 presents the top-10 venues with the highest number of publications. While eight of the top-10 publication venues belong to the software engineering research field, two conferences are from the information systems research field. The top six venues account for 50% of all publications, while the remaining 40 venues cover half of all studies. The top venues are the International Conference on Agile Software Development, followed by the International Workshop on Large-Scale Agile Development. Both venues have at least twice as many publications as the third-largest contributor, the International Conference on Global Software Engineering. The top contributing journals are IEEE Software and Information and Software Technology. The publication venues' distribution indicates that contributions are published primarily at the International Conference on Agile Software Development and International Workshop on Large-Scale Agile Development, which is unsurprising as they deal exclusively with this topic. Researchers and practitioners can consider these venues as an entry point to explore the state of the art in large-scale agile development research and gain easier access to the community. We note that several studies are present in leading software engineering journals, e.g., IEEE Software, Information and Software Technology, and Empirical Software Engineering. Since six publication venues cover half of all publications, we assume that researchers primarily submit their research to a few specific venues. The publication venues' distribution shows a long tail of 27 venues, each with one published study.

4.2.4. Research types and methods

Fig. 18 shows the distribution of selected studies against their research types. We only identified three research types of the six research types specified by Wieringa et al. (2006) (see Table 5), namely evaluation research, solution proposal, and philosophical papers. We note that 110 articles report on evaluating solutions applied in practice, typically through case studies, mixed methods, surveys, or similar empirical methods. Solution proposals were the next most frequently covered research type presenting either novel solutions or significant extensions of existing solutions. Philosophical papers that offer new perspectives on existing things by framing the large-scale agile development field using conceptual frameworks or taxonomies were the third most commonly identified research type. Based on our selection criteria (see Section 3.2.2), we could not identify any experience and opinion papers since they were excluded during our selection process. We could also not identify any validation research studies in which researchers investigate novel techniques that have not yet been implemented in practice. This observation would also have been atypical as most of the selected articles are concerned with identifying, describing, and evaluating the practical application of agile methods on a larger scale. The fact that evaluation research is widely used positively impacts the potential for transferring current research findings to the industry. The prevalence of evaluation research studies is natural in a phenomenon such as large-scale agile development, which is driven primarily by industry instead of resulting from the context of a research lab.

Fig. 19 shows the evolution of research types over time. We notice that evaluation research studies dominate large-scale agile

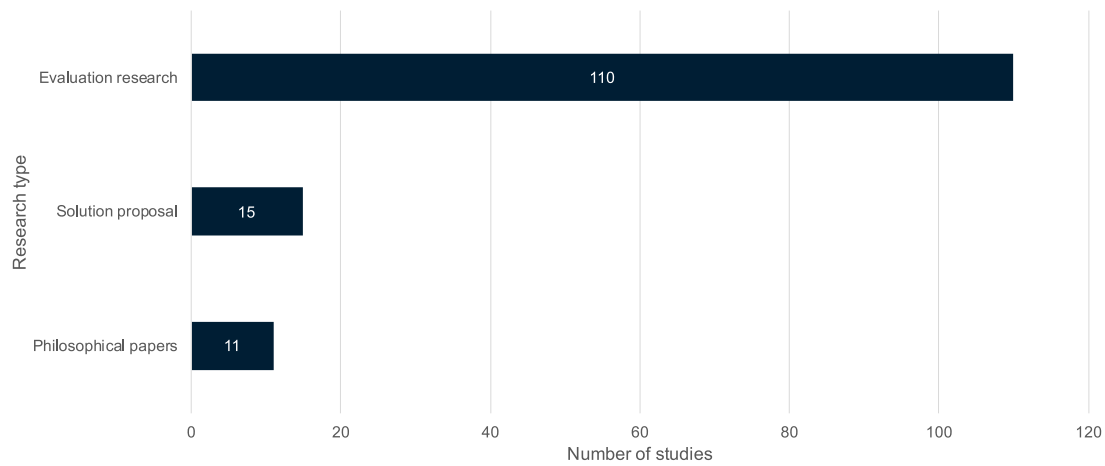


Fig. 18. Distribution of research types.

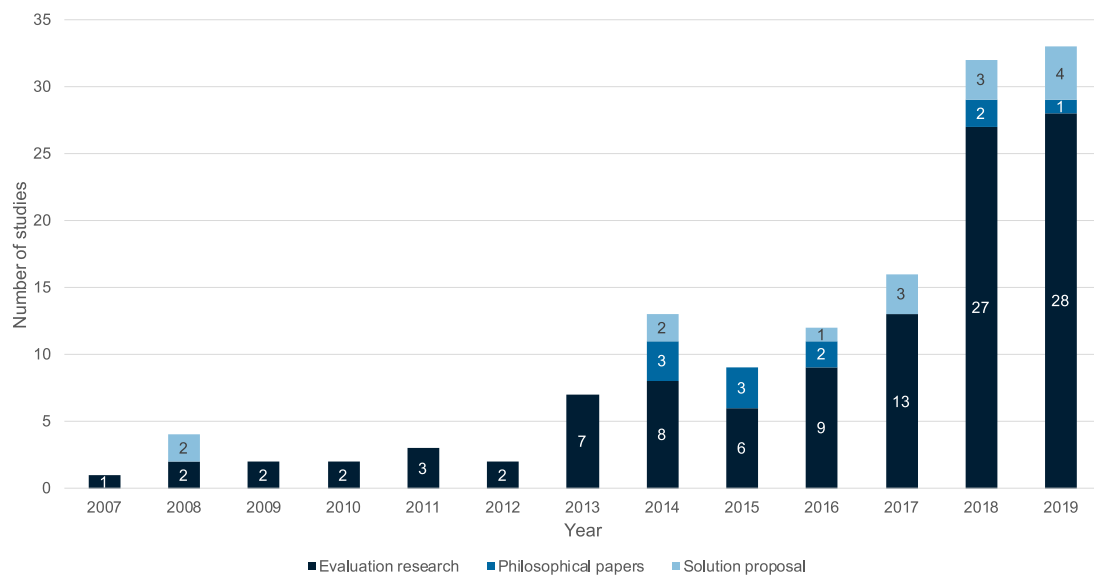


Fig. 19. Number of studies per research type over time.

development research throughout the period considered, especially before 2013, when 12 out of 14 papers belong to this category. Accordingly, before 2013, only two articles were published from the solution proposal research type. After 2013, an increasing tendency towards all three identified research types can be observed. While between 2014 and 2019, at least six evaluation research papers were published each year, at least three articles per year were published combining philosophical papers and solution proposals. As a result, we observe a promising development in large-scale agile development research, i.e., researchers evaluate existing techniques in practice and develop new solutions based on their observations and frame the observed phenomena using conceptual models.

To investigate research methods applied in large-scale agile development, we visualize the research approaches used in the selected studies in Fig. 20. Most studies are empirical and include case studies, mixed methods, ground theory, survey, design and creation, and action research. By far, the most prevalent research method in large-scale agile development is case study research, followed by (systematic) literature review/(systematic) mapping study, mixed methods, and grounded theory. We could not identify the applied research method in seven articles, as it was neither described nor derivable. Only three papers are theoretical,

mainly in the form of conceptual models. For instance, [Carroll and Conboy \(2019\)](#) apply normalization process theory to theorize the process of large-scale agile transformations by identifying existing assumptions about these transformations and explaining what factors enable their normalization. [Sweetman and Conboy \(2018\)](#) use the complex adaptive systems lens to critically appraise current thinking on portfolio management in an agile context. We identified only one action research paper, namely the from [Pries-Heje and Krohn \(2017\)](#), that describes the adoption of SAFe at SimCorp and the resulting implementation challenges using a participatory action research project. The results show that the body of knowledge on large-scale agile development is mainly empirical and is still at an exploratory stage. A high percentage of articles are case studies that are sparsely based on grounded theory or theory-building methods.

To reveal trends, we visualize the annual distribution of applied research approaches over time in Fig. 21. Fig. 21 confirms the prevalence of case study research from a temporal perspective, i.e., case study research was applied throughout the entire observation period and shows a nearly constant increase over time, peaking in 2018 and 2019. Between 2007 and 2013, 76.19% of the studies were based on case study research. At the same time, only four out of the eight identified research

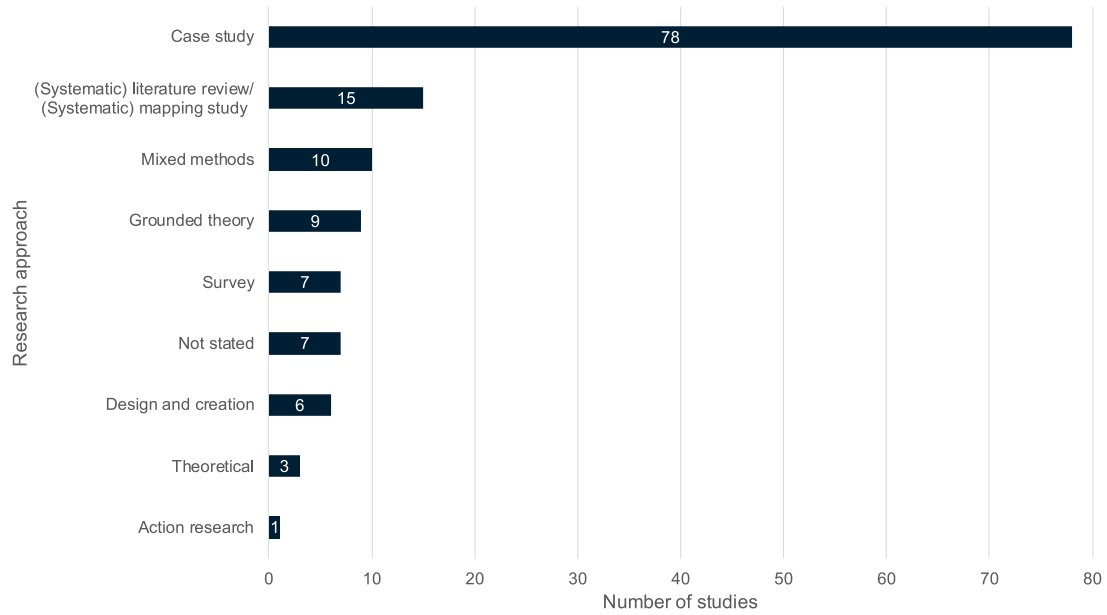


Fig. 20. Distribution of applied research approaches.

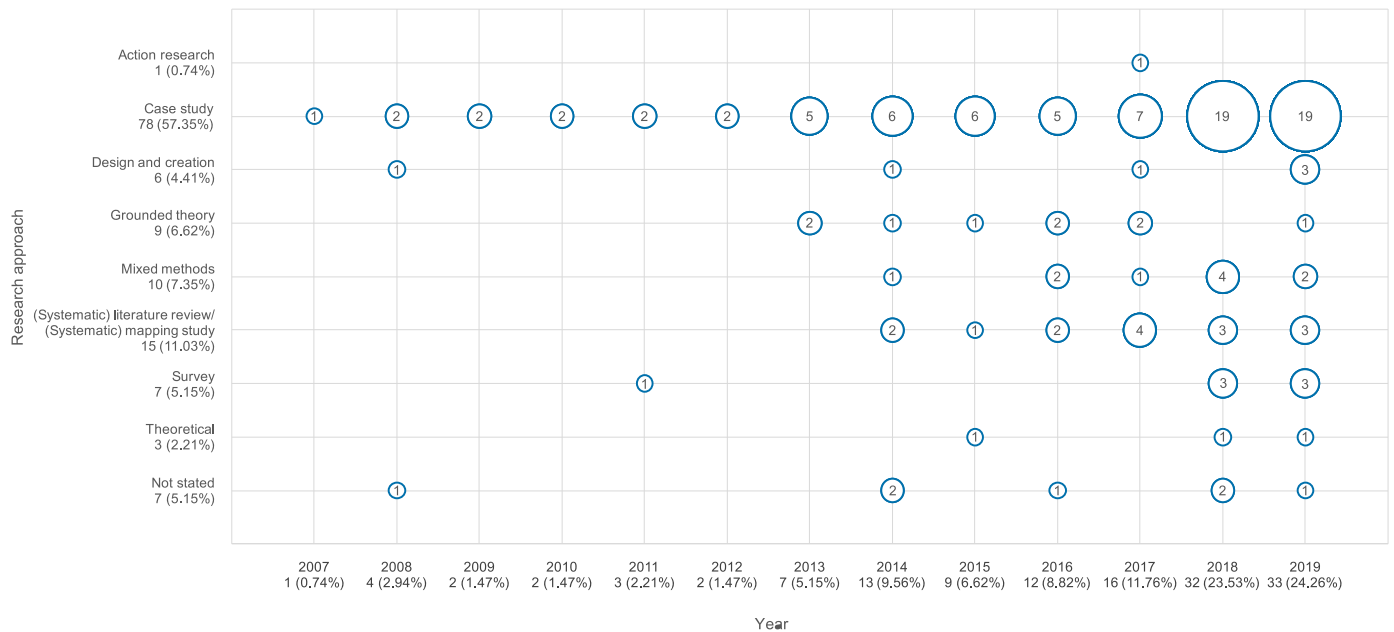


Fig. 21. Number of studies per research approach over time.

approaches, i.e., case study, design and creation, grounded theory, and survey. As of 2014, the remaining four research methods, i.e., action research, mixed methods, (systematic) literature review/(systematic) mapping study, and theoretical, were applied. The most diverse usage of research approaches was observed in 2019, when seven different research methods were used. The increasing use of various research methods validates our view that large-scale agile development is a multifaceted research field necessitating the investigation of the observation object from different scientific angles. This trend demonstrates the increasing demand from companies for academic support, which fuels the growing research interest of scholars.

4.2.5. Research outcomes

Fig. 22 shows the distribution of research contributions of the 136 selected studies. A total of 115 papers contribute in

the form of lessons learned and guidelines. They are rather observational by analyzing and describing the application of agile practices in large-scale projects. Conversely, the remaining studies contribute models, frameworks/methods, and theories. For instance, [Qumer and Henderson-Sellers \(2008\)](#) propose a new framework called Agile Software Solution Framework to support the adoption and improvement of agile methods in large-scale software projects. Using the human systems dynamics model, [Power \(2014\)](#) presents a new model to determine when scaling agile practices is appropriate for large organizations. [Bass \(2016a\)](#) provides another example and uses the Glaserian grounded theory approach to study and explain artifact inventories used in large-scale agile offshore software programs. None of the selected studies contribute to developing new or improved tools. This observation suggests that further research is needed that develop conceptual models and theories to strengthen the theoretical

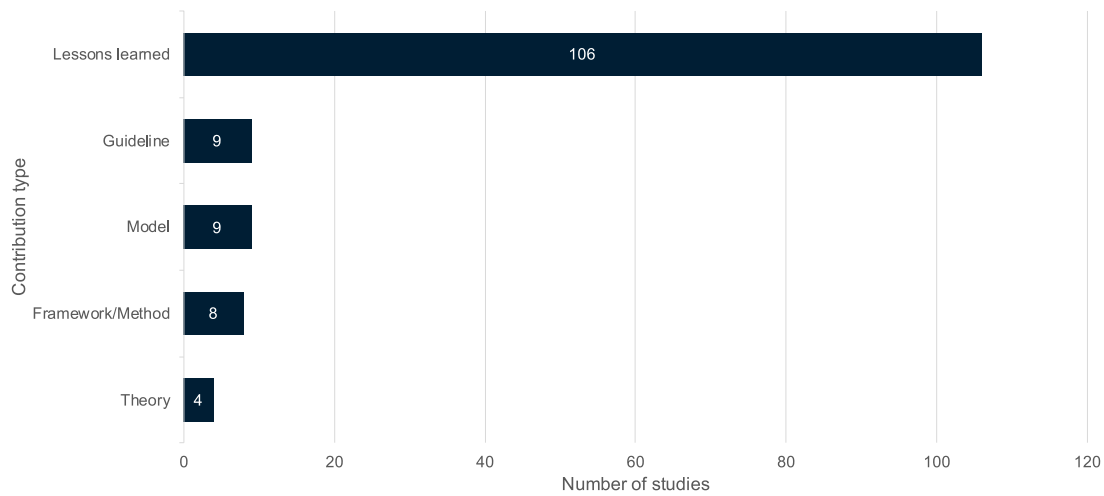


Fig. 22. Distribution of research outcomes.

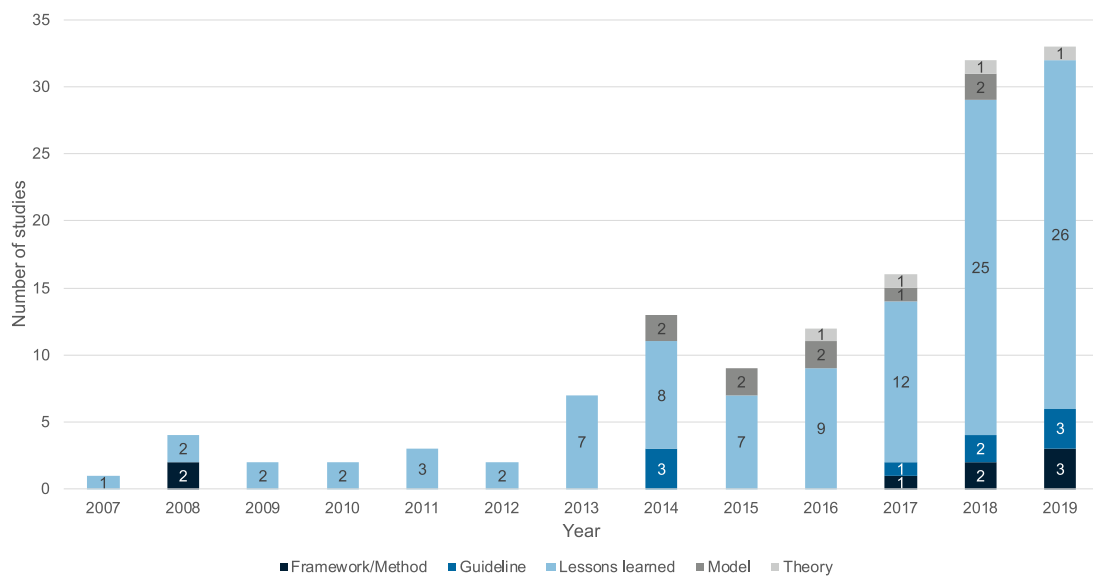


Fig. 23. Distribution of research outcomes over time.

foundations of large-scale agile development research and create rigorously developed frameworks, methods, and tools to assist practitioners.

Fig. 23 shows an annual distribution of the contribution type facet. Most articles focused on deriving lessons learned from observations made on large-scale agile endeavors between 2007 and 2019. During this period, at least one lessons learned study was published annually, peaking in 2018 and 2019. Starting in 2014, with at least two published studies per year, a clear tendency towards creating frameworks/methods, models, and theories can be observed. This observation indicates growing empirical evidence owing to the rising interest in the research community and the growing body of knowledge.

To spot possible patterns between the publications domains' preference for made contribution types and applied research approaches, Fig. 24 displays the relationship between these three data items. We can see that in almost all domains, except for IT project management, deriving lessons learned from observations made is the most common contribution type. We note that most diverse contributions have been made in the software engineering field, confirming its multidisciplinary nature (cf. Hannay et al., 2007) even in the context of large-scale agile development.

Concerning the relationship between publication domains and research methods, we notice that case study research is preferred in most domains. Although case study research is the most commonly used approach in the information systems and software engineering domains, we realize that these two domains use a wide variety of research methods.

To better understand the relation between the research outcome and the applied research type and approach of each study, we visualize the relationship between these three data items in Fig. 25. The predominance of the selected articles applies case study research to evaluate the usage of agile methods in large-scale projects and derive a set of lessons learned based on the analysis of the research findings. In terms of evaluation research, the remaining articles apply various research methods, mainly (systematic) literature reviews/(systematic) mapping studies, mixed methods, and surveys, to draw some lessons learned. Further 17 papers use case study research, design and creation research, grounded theory, and mixed methods research to make contributions in the form of taxonomies, conceptual frameworks, and theories. For instance, by applying grounded theory, Santos et al. (2015) create a conceptual model that aims to explain the dependence of adequate knowledge sharing across

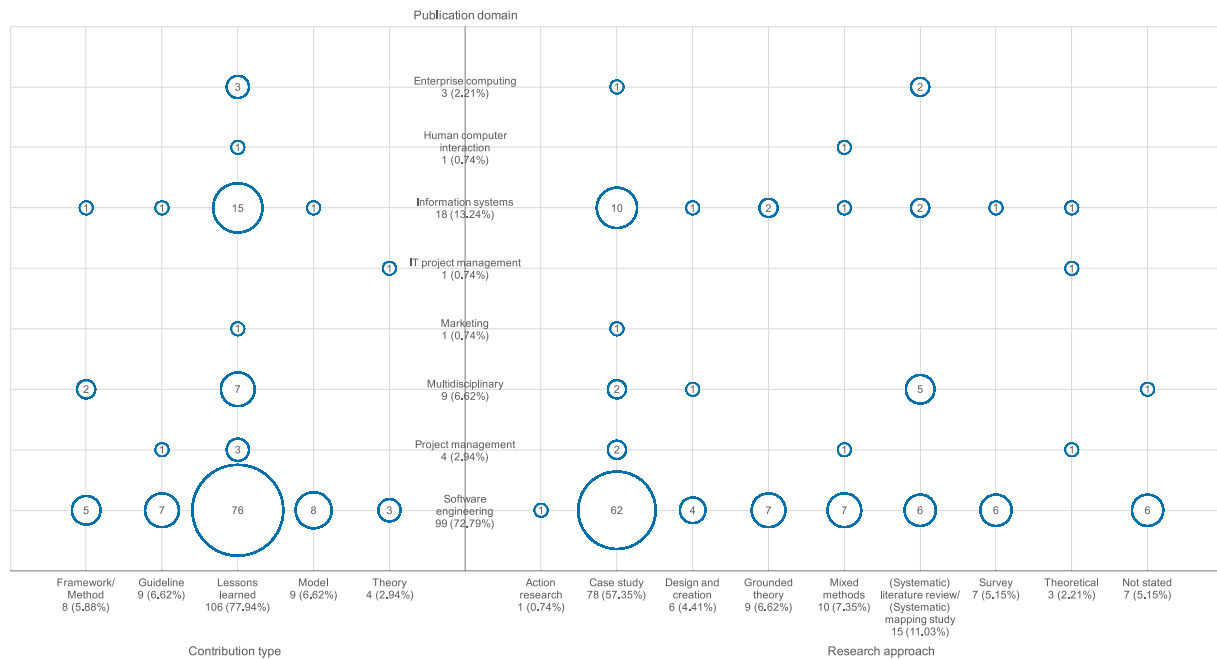


Fig. 24. Mapping of publication domains against contribution types and research approaches.

agile teams on the purposeful application of agile practices and organizational conditions and stimuli. Turetken et al. (2017) propose a maturity model to assess the degree of adopting SAFe in companies using design science research. Rolland et al. (2016) employ a mixed methods research design consisting of a literature review and case study to create a conceptual model for examining the underlying assumptions of large-scale agile development. By comparing contribution types and research types and methods, the under-representation of the usage of systematic literature reviews/systematic mapping studies and surveys becomes apparent. Only 16.18% of the studies use (systematic) literature reviews/(systematic) mapping studies and surveys to contribute in terms of lessons learned. These approaches are non-existent in other contribution types. This observation indicates a research gap in creating new conceptual models or adapting existing theoretical models from different research domains to explain the various aspects of large-scale agile development based on quantitative surveys and statistical analyses.

4.2.6. Research data types

While 121 of the selected papers are primary studies and another 15 articles are secondary studies, we did not find any tertiary studies. Six secondary studies provide ad hoc (systematic) literature reviews on challenges and success factors of applying agile methods in large (and distributed) software projects (cf. Shameem et al., 2018a; Dikert et al., 2016; Uludağ and Matthes, 2019; Shameem et al., 2017; Saeeda et al., 2015; Ravazi and Ahmad, 2014). Four secondary studies compare and analyze various scaling agile frameworks based on (systematic) literature reviews (cf. Alqudah and Razali, 2016; Theobald et al., 2019; Uludağ et al., 2017; Ozkan and Tarhan, 2019). Based on a literature review, one secondary study identifies roles responsible for inter-team coordination of agile teams (cf. Gustavsson, 2017). One secondary study reveals a set of motivators for large-scale adoption of agile methods from a management perspective (cf. Abrar et al., 2019). One secondary study provides a multi-vocal literature review describing the benefits and challenges of adopting SAFe (cf. Putta et al., 2018). One secondary study conceptualizes coordination in large-scale agile development from a multi-team systems perspective (cf. Scheerer et al., 2014). One secondary

study provides a set of challenges that harm quality requirements in large-scale distributed agile projects and proposes a set of solutions to overcome them (cf. Alsaqaf et al., 2017).

Fig. 26 shows an annual distribution of the research data type facet. Alongside the sharp increase in the number of published studies over the past decade, secondary studies have also increased in recent years. Specifically, all secondary studies were published after 2013. The increase of secondary studies indicates the growing body of knowledge and maturity of the large-scale agile development research field.

4.3. Seminal studies

As suggested by Dingsøyr et al. (2012) and Nerur et al. (2008), we identified seminal works as they facilitate understanding and exploration of the intellectual structure of the large-scale agile development research field. Like Herbold et al. (2021), we extracted data on citation numbers from Google Scholar to define our criterion for seminal publications and consider the top 10% of the studies with the most citations as influential (see Table 10). The 13 seminal publications:

1. discuss effects, issues, benefits, and success factors related to the large-scale introduction of agile practices in plan-driven organizations (cf. Petersen and Wohlin, 2009, Laanti et al., 2011, Bjarnason et al., 2011b, Dikert et al., 2016, Petersen and Wohlin, 2010b),
2. describe experiences in applying agile practices based on Scrum to large, globally distributed software development programs (cf. Paasivaara et al., 2008a, Paasivaara et al., 2008b),
3. present the role of communities of practices and the associated challenges and success factors as part of large-scale agile transformations (cf. Paasivaara and Lassenius, 2014),
4. propose a scaling framework for creating new agile software development processes to develop large and complex software applications (cf. Qumer and Henderson-Sellers, 2008),

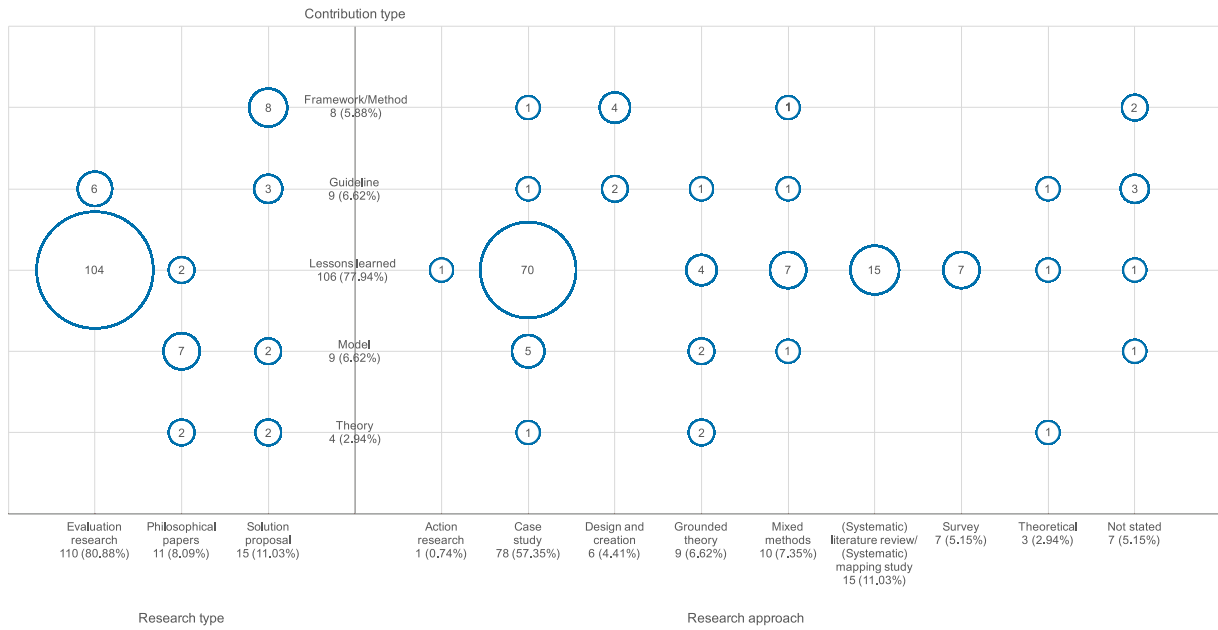


Fig. 25. Mapping of contribution types against research types and approaches.

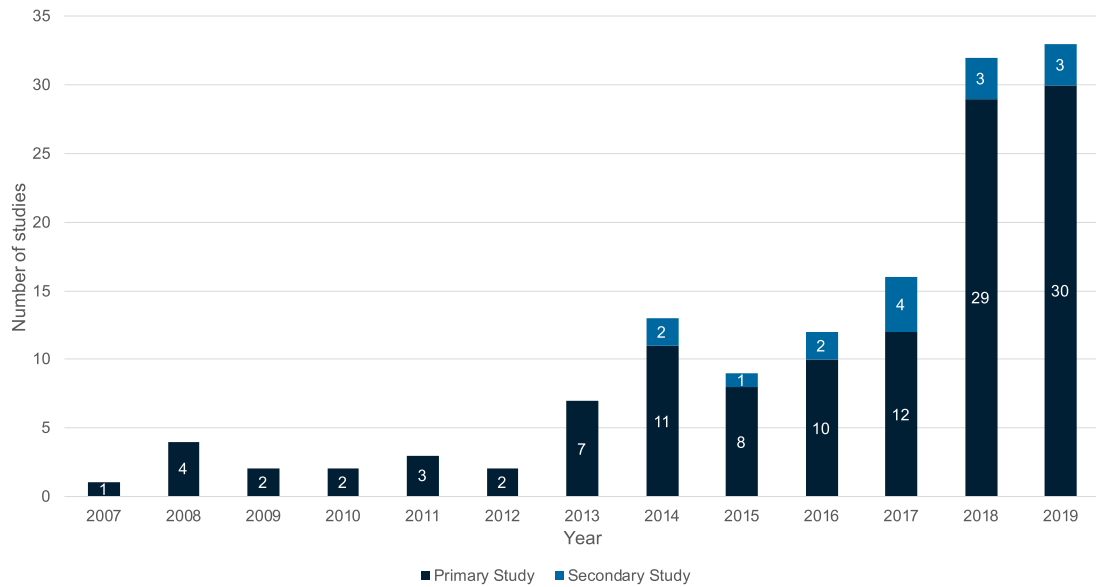


Fig. 26. Distribution of used research data types over time.

- propose a framework for guiding software process improvement activities concerning agility in large software product development organizations (cf. [Kettunen and Laanti, 2008](#)),
- elucidate the adaption of agile methods in terms of customer involvement, software architecture, and inter-team coordination in a large-scale agile program (cf. [Dingsøyr et al., 2018b](#)),
- report the application of the scaling approach SoS and its associated challenges and success factors in large-scale distributed Scrum projects (cf. [Paasivaara et al., 2012b](#)), and
- describe the adoption of portfolio management practices and the associated benefits and side-effects in organizations applying agile methods at large-scale (cf. [Stettina and Hörz, 2015](#)).

4.4. Research streams and research agenda in large-scale agile development

As a common goal of systematic mapping studies is to assess the state of the art and maturity level of a research area ([Petersen et al., 2008](#); [Kitchenham et al., 2011](#)), we present the general structure, central research themes, and research gaps of the large-scale agile development research field. Below we present our key findings related to the identified research streams and gaps before discussing each of them.

4.4.1. General overview

We explored research clusters to identify pertinent research themes and structured the selected studies according to these themes. [Fig. 27](#) provides an overview of the identified research streams and shows the number of studies assigned to each

Table 10

Top 10% of publications ranked by number of citations according to Google Scholar (data collected on 2019-12-31).

Study	Title	Authors	Publication type	Year	No. of citations	Citations per year
Dikert et al. (2016)	Challenges and success factors for large-scale agile transformations: a systematic literature review	Kim Dikert , Maria Paasivaara , Casper Lassenius	Journal	2016	273	68
Qumer and Henderson-Sellers (2008)	A framework to support the evaluation, adoption and improvement of agile methods in practice	Asif Qumer , Brian Henderson-Sellers	Journal	2008	256	21
Petersen and Wohlin (2009)	A comparison of issues and advantages in agile and incremental development between state of the art and an industrial case	Kai Petersen , Claes Wohlin	Journal	2009	229	21
Laanti et al. (2011)	Agile methods rapidly replacing traditional methods at nokia: a survey of opinions on agile transformation	Maarit Laanti , Outi Salo , Pekka Abrahamsson	Journal	2011	227	25
Petersen and Wohlin (2010b)	The effect of moving from a plan-driven to an incremental software development approach with agile practices: an industrial case study	Kai Petersen , Claes Wohlin	Journal	2010	166	17
Stettina and Hörz (2015)	Agile portfolio management: an empirical perspective on the practice in use	Christoph J. Stettina , Jeanette Hörz	Journal	2015	126	25
Paasivaara et al. (2008a)	Distributed agile development: using scrum in a large project	Maria Paasivaara , Sandra Durasiewicz , Casper Lassenius	Conference	2008	119	10
Paasivaara et al. (2008b)	Using scrum in a globally distributed project: a case study	Maria Paasivaara , Sandra Durasiewicz , Casper Lassenius	Journal	2008	101	8
Paasivaara and Lassenius (2014)	Communities of practice in a large distributed agile software development organization – case ericsson	Maria Paasivaara , Casper Lassenius	Journal	2014	98	16
Paasivaara et al. (2012b)	Inter-team coordination in large-scale globally distributed scrum: do scrum-of-scrums really work?	Maria Paasivaara , Casper Lassenius , Ville T. Heikkilä	Conference	2012	91	11
Bjarnason et al. (2011b)	A case study on benefits and side-effects of agile practices in large-scale requirements engineering	Elizabeth Bjarnason , Krzysztof Wnuk , Björn Regnell	Workshop	2011	87	10
Kettunen and Laanti (2008)	Combining agile software projects and large-scale organizational agility	Petri Kettunen , Maurit Laanti	Journal	2008	86	7
Dingsøyr et al. (2018b)	Exploring software development at the very large-scale: a revelatory case study and research agenda for agile method adaptation	Torgeir Dingsøyr , Nils B. Moe , Tor E. Fægri , Eva A. Seim	Journal	2018	83	42

stream. We identified 10 research streams, namely *Agile architecture*, *Agile planning*, *Agile portfolio management*, *Agile practices at scale*, *Communication and coordination*, *Global and distributed software engineering*, *Large-scale agile transformations*, *Scaling agile frameworks*, *Taxonomy*, and *Team autonomy*. While some research streams have enjoyed very little research interest, e.g., *Taxonomy* or *Agile portfolio management*, researchers have devoted a great deal of attention to investigating the scaling of agile practices, i.e., *Agile practices at scale*, studying the coordination of large agile multi-team settings, i.e., *Communication and coordination*, and analyzing the adoption of scaling frameworks, i.e., *Scaling agile frameworks*.

Table 11 shows a tabular representation of the research streams, including their sub-topics. While most research streams exhibit numerous endeavors and clusters dealing with specialized sub-topics, some research streams scarcely show any specific sub-research cluster. For instance, in the research stream *Communication and coordination*, we identified several sub-topics, e.g., *Communication mechanisms*, *Team performance*, and *Knowledge networks*, while we did not observe any specialized sub-themes in the *Team autonomy* and *Taxonomy* research streams.

In almost all research streams (except *Taxonomy*), we observe several studies that derived several lessons learned in the form of challenges and success factors based on their investigations. The complexity and the number of sub-clusters identified per research stream are logically reflected in the number of studies assigned to a stream. While only three papers were assigned to the *Taxonomy* research stream with no specialized sub-topic, nine sub-streams were identified in the *Agile practices at scale* research stream.

Fig. 28 visualizes how the number of studies assigned to the research streams has developed over time. The earliest researches on large-scale agile development were conducted between 2007 and 2008 and are related to the *Agile practices at scale*, *Global and distributed software engineering*, and *Scaling agile frameworks* research streams. [Tessem and Maurer \(2007\)](#) represent the first reported paper on large-scale agile development belonging to *Agile practices at scale* research stream and describing the adaptation of Scrum for a project involving 70 people. The initial contributions to the four research streams: *Agile architecture*, *Team autonomy*, *Communication and coordination*, and *Taxonomy* were published between 2013 and 2016, when a great interest in

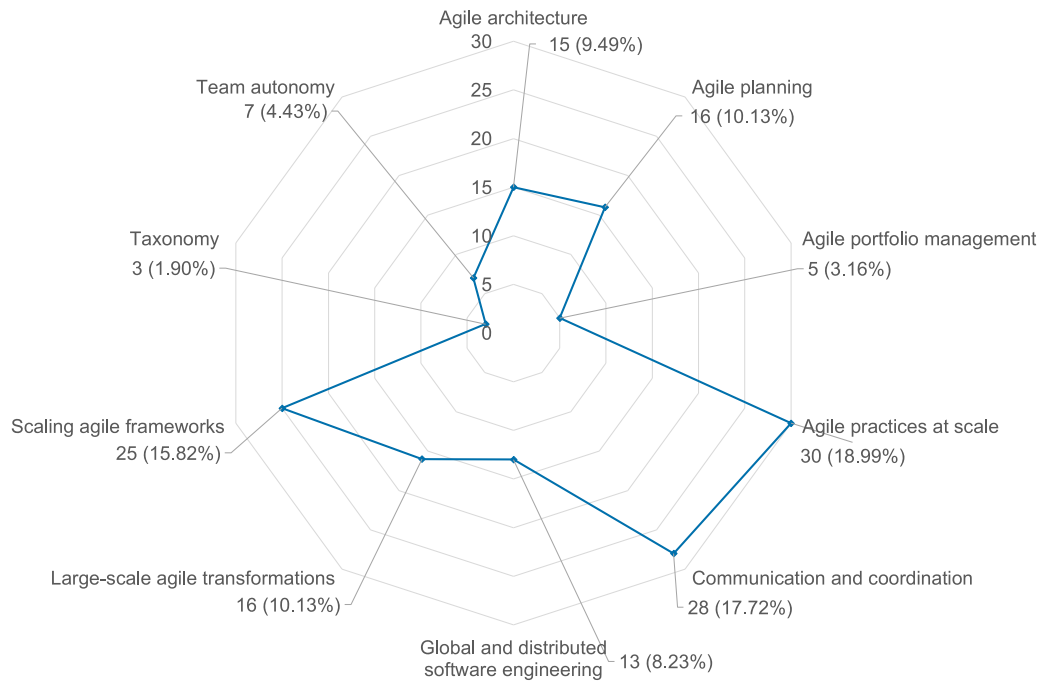


Fig. 27. Distribution of the studies in the different research streams.

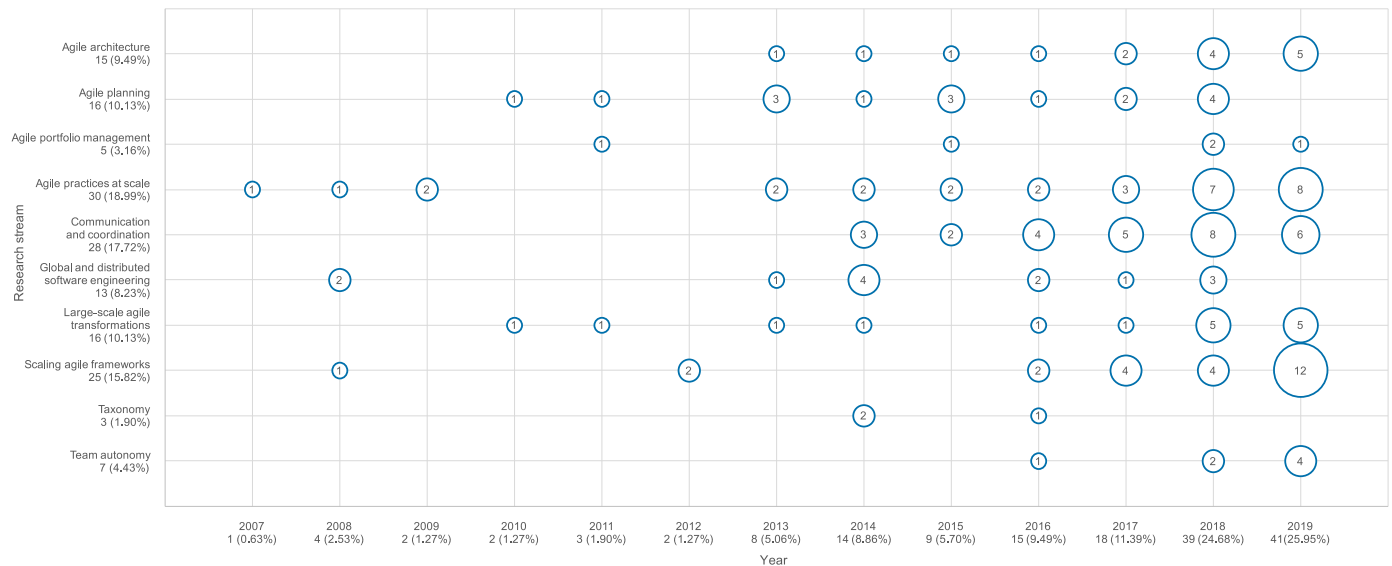


Fig. 28. Number of studies per research stream over time.

the large-scale agile development research topic emerged. After 2013, there has been a general increase in research interest in all research streams (except *Taxonomy*). The *Scaling agile frameworks* research stream shows a steady research interest between 2016 and 2019, with a peak in 2019, accounting for almost one-third of all published studies in 2019. This observation is congruent with [Uludağ et al. \(2021\)](#) stating that many scaling frameworks were created and published between 2011 and 2018, confirming the increasing industry interest in scaling frameworks and sparking a growing interest in analyzing the adoption of these frameworks. Furthermore, 56.25% of all studies published between 2018 and 2019 were related to *Agile practices at scale*, *Communication and coordination*, and *Scaling agile frameworks*, while the remaining seven streams accounted for 43.75% of all studies.

Following [Kitchenham et al. \(2011\)](#), we derive a research agenda that scholars can use. [Fig. 29](#) shows the number of research questions identified for each research stream. We identified 81 research questions that were mapped to the respective streams (see [Table 12](#)). Most research questions were identified in the *Communication and coordination*, *Agile architecture*, and *Agile planning* research streams.

Next, we discuss the research streams and gaps reported in the selected studies.

4.4.2. Agile architecture

Agile methods imply that architecture emerges from the system rather than being imposed by some direct structuring force ([Babar, 2009](#)). The practice of emergent design is effective at the team level but insufficient when agile methods are applied at a larger scale, as large-scale agility is enabled by architecture,

Table 11

Tabular overview of research streams on large-scale agile development.

Research stream	Influential studies	Topic level 1/Study	Topic level 2/Study	Topic level 3/Study
Agile architecture	Dingsøyr et al. (2018b)	Software architecture	Software reuse	Martini et al. (2013)
			Role of software architects	Dingsøyr et al. (2018b), Uludağ et al. (2017), Britto et al. (2016) and Uludağ et al. (2019c)
		Enterprise architecture	Technical debts	Martini et al. (2019)
			Challenges and success factors	Duijs et al. (2018) and Thummadi et al. (2017)
			Role of enterprise architects	Uludağ et al. (2017) and Uludağ et al. (2019d)
		Architecture principles	Gundelsby (2018), Uludağ et al. (2019e) and Uludağ et al. (2019f)	–
		Domain-driven design	Uludağ et al. (2018a)	–
		Models	Martini et al. (2015)	–
		Patterns	Nord et al. (2014b)	–
		Effort estimation	Usman et al. (2018)	–
Agile planning	Bjarnason et al. (2011b) and Dingsøyr et al. (2018b)	Release planning process	Heikkilä et al. (2010), Heikkilä et al. (2013), Heikkilä et al. (2017) and Heikkilä et al. (2015b)	–
		Challenges and success factors	Bjarnason et al. (2011b), Evbota et al. (2016), Badampudi et al. (2013), Sekitoleko et al. (2014), Alsaqaf et al. (2018), Theobald and Diebold (2018) and Alsaqaf et al. (2017)	–
		Customer involvement	Olsson et al. (2013), Dingsøyr et al. (2018b), Olsson and Bosch (2015) and Lindsjörn and Moustafa (2018)	–
		Not specified	Fægri and Moe (2015)	–
		Challenges and success factors	Rautiainen et al. (2011), Stettina and Hörz (2015), Sweetman and Conboy (2018) and Stettina and Schoemaker (2018)	–
		Patterns	Horlach et al. (2019)	–
		Tailoring	Bass (2013), Bass (2016a), Bass (2016b), Bass (2014) and Bass and Haxby (2019)	–
		Kanban	Tripathi et al. (2015)	–
		Retrospectives	Dingsøyr et al. (2018a)	–
		Communities of practices	Paasivaara and Lassenius (2014), Paasivaara and Lassenius (2019), Šmite et al. (2019a) and Šmite et al. (2019b)	–
Agile practices at scale	Petersen and Wohlin (2009), Paasivaara and Lassenius (2014) and Kettunen and Laanti (2008)	Rapid application development	Berger and Beynon-Davies (2009)	–
		Challenges and success factors	Uludağ et al. (2019a), Uludağ et al. (2018b), Uludağ and Matthes (2019), Kalenda et al. (2018), Tessem and Maurer (2007) and Saeeda et al. (2015)	–
		Models	Turetken et al. (2017), Kettunen and Laanti (2008), Weiss and Brune (2017), Uludağ et al. (2019e), Uludağ et al. (2018a) and Schuh et al. (2018)	–
		Patterns	Uludağ et al. (2019a) and Uludağ et al. (2018b)	–
		Not specified	Petersen and Wohlin (2009), Jørgensen (2019), Lagerberg et al. (2013), Hobbs and Petit (2017) and Jørgensen (2018)	–
		Inter-team coordination	Multiteam systems	Scheerer et al. (2014), Bick et al. (2016), Bjørnson et al. (2018) and Scheerer et al. (2015)
			Coordination mechanisms	Gustavsson (2017), Dingsøyr et al. (2018c), Dingsøyr et al. (2017), Gustavsson (2019c), Dingsøyr et al. (2018b), Nyrud and Stray (2017), Stray (2018), Gustavsson (2018b), Berntzen et al. (2019), Moe et al. (2018) and Gustavsson (2019b)
Communication and coordination	Dingsøyr et al. (2018b)	Inter-team coordination	Multiteam systems	Scheerer et al. (2014), Bick et al. (2016), Bjørnson et al. (2018) and Scheerer et al. (2015)
			Coordination mechanisms	Gustavsson (2017), Dingsøyr et al. (2018c), Dingsøyr et al. (2017), Gustavsson (2019c), Dingsøyr et al. (2018b), Nyrud and Stray (2017), Stray (2018), Gustavsson (2018b), Berntzen et al. (2019), Moe et al. (2018) and Gustavsson (2019b)

(continued on next page)

Table 11 (continued).

Research stream	Influential studies	Topic level 1/Study	Topic level 2/Study	Topic level 3/Study
			Team performance	Gustavsson (2018a) and Lindsjörn et al. (2018)
			Challenges and success factors	Bick et al. (2018) and Nyfjord et al. (2014)
		Knowledge sharing	Software ecosystems	Figalist et al. (2019)
			Knowledge boundaries	Rolland (2016)
			Knowledge networks	Šablīs and Šmite (2016), Moe et al. (2014), Šmite et al. (2017) and Uludağ et al. (2019c)
			Not specified	Santos et al. (2015), Bjørnson and Vestues (2016) and Šmite et al. (2019a)
Global and distributed software engineering	Paasivaara et al. (2008a) and Paasivaara et al. (2008b)	Challenges and success factors	Shameem et al. (2018a), Paasivaara et al. (2008a), Papadopoulos (2015), Shameem et al. (2018c), Shameem et al. (2017), Paasivaara et al. (2014a), Paasivaara et al. (2008b) and Ravazi and Ahmad (2014)	–
		Offshoring and outsourcing	Bass (2013), Bass (2016a), Bass (2016b) and Bass (2014)	–
		Not specified	Usman et al. (2018)	–
Large-scale agile transformations	Laanti et al. (2011), Dikert et al. (2016) and Petersen and Wohlin (2010b)	Challenges and success factors	Laanti et al. (2011), Gerster et al. (2018), Fuchs and Hess (2018), Dikert et al. (2016), Lal and Clear (2018), Paasivaara et al. (2013), Paasivaara et al. (2018), Abrar et al. (2019), Petersen and Wohlin (2010b), Jovanović et al. (2017), Barroca et al. (2019b), Karvonen et al. (2018) and Kettunen et al. (2019)	–
		Agile mindset	Uludağ et al. (2018b) and Paasivaara et al. (2014b)	–
		Theory building	Carroll and Conboy (2019)	–
Scaling agile frameworks	Qumer and Henderson-Sellers (2008) and Paasivaara et al. (2012b)	Challenges and success factors	Conboy and Carroll (2019)	–
		Large-Scale Scrum	Paasivaara et al. (2012a), Uludağ et al. (2019b) and Paasivaara and Lassenius (2016)	–
		Scaled Agile Framework	Paasivaara (2017), Turetken et al. (2017), Gustavsson (2019c), Gustavsson (2018b), Pries-Heje and Krohn (2017), Gustavsson (2019b), Gustavsson (2019a), Putta et al. (2019), Laanti and Kettunen (2019) and Putta et al. (2018)	–
		Scrum-of-Scrums	Paasivaara et al. (2012b)	–
		Spotify Model	Salameh and Bass (2019), Gerster et al. (2019) and Šmite et al. (2019a)	–
		Agile Software Solution Framework	Qumer and Henderson-Sellers (2008)	–
		Disciplined Agile Delivery		–
		Framework comparisons	Lal and Clear (2018)	–
			Alqudah and Razali (2016), Theobald et al. (2019), Uludağ et al. (2017), Diebold et al. (2018) and Ozkan and Tarhan (2019)	–
Taxonomy		Not specified	Power (2014), Rolland et al. (2016) and Dingsøyr et al. (2014)	–
Team autonomy		Challenges and success factors	Moe et al. (2019a), Gundelsby (2018), Mikalsen et al. (2019) and Gustavsson (2019a)	–
		Governance	Šablīs and Šmite (2016), Tendedez et al. (2018) and Petit and Marnewick (2019)	–

and vice versa (Leffingwell et al., 2008, Uludağ et al., 2019d). The topic of agile architecture is gaining attraction among agilists and researchers (cf. Freudenberg and Sharp, 2010; Nord et al., 2014a; Rost et al., 2015). The *Agile architecture* research stream aims to address the questions of how companies can combine the at first glance contradictory topics of agility and architecture

to build complex products and how agile teams can be jointly architecturally aligned at the enterprise level. As the topic of agile architecture is multi-faceted, we identified six sub-topics in the *Agile architecture* stream. The first two sub-topics address agile architecture research at different organizational levels, e.g., at product level, i.e., software architecture, and enterprise level,

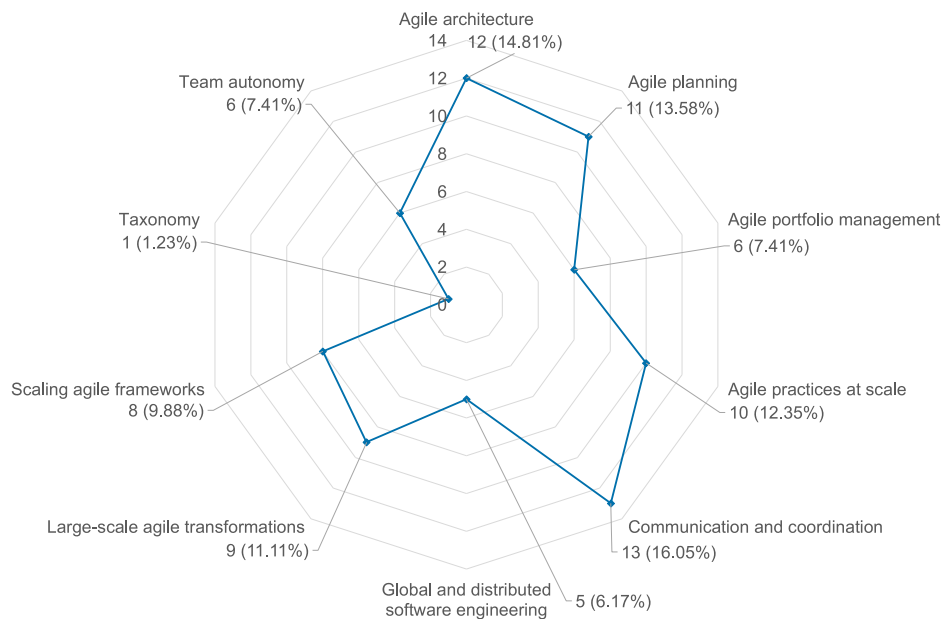


Fig. 29. Distribution of research questions in the different research streams.

i.e., enterprise architecture (cf. Martini et al., 2013, Britto et al., 2016, Thummadi et al., 2017). Due to the multitudinousness of the agile architecture topic, we also identified several sub-topics related to software and enterprise architecture sub-topics. Within the software architecture sub-topic, extant literature aims to describe how software reuse can be facilitated in large-scale agile endeavors (cf. Martini et al., 2013) and how technical debts can be managed in large-scale agile projects (cf. Martini et al., 2019). Several studies also aim to clarify the roles and responsibilities of software architects in large-scale agile projects (cf. Dingsøyr et al., 2018b, Britto et al., 2016, Uludağ et al., 2019c). In the enterprise architecture sub-topic, we identified two additional sub-topics that aim to answer the questions on how enterprise architecture efforts can be effectively adopted in agile environments (cf. Duijs et al., 2018, Thummadi et al., 2017) and how enterprise architects can support agile teams (cf. Uludağ et al., 2017, Uludağ et al., 2019d). The remaining four sub-topics introduce commonly applied architectural toolboxes, i.e., architecture principles, domain-driven design, models, and patterns (cf. Gundelsby, 2018, Uludağ et al., 2018a, Martini et al., 2015, Nord et al., 2014b). Notable results of the *Agile architecture* research stream are:

- Observations indicating that an upfront architecture provides agile teams with a stable working environment contributes to team efficiency and that the role of architects is demanding, requiring continuous coordination with many stakeholders (Dingsøyr et al., 2018b).
- An organizational framework, including roles, teams, and practices, to address challenges related to agile architecting in large-scale agile projects (Martini et al., 2015).
- A set of architectural tactics for addressing architectural concerns in large-scale agile projects, e.g., the runway-building tactic, which can be used when architecture is needed that is sufficient to meet near-term needs without causing delays or additional work (Nord et al., 2014b).

Observations suggesting that an upfront architecture provides agile teams with a stable working environment that likely contributes to team efficiency, and that the role of architects in large-scale agile development is challenging and requires ongoing coordination and negotiation among many stakeholders

Agile methods have been criticized for their lack of focus on architecture (Dybå and Dingsøyr, 2008), assuming that the best architectures emerge from self-organizing teams (Babar, 2009; Abrahamsson et al., 2010). For instance, the incremental design practice of XP asserts that architecture emerges in daily design (Beck, 2000; Babar, 2009). Apart from verbal discussions of design decisions, Scrum does not emphasize architecture-related practices as the architecture of a single-project application can always be re-factored and repackaged for a higher level of reuse (Babar, 2009). There is growing interest from academics and practitioners who wish to combine the two concepts of agility and architecture as some degree of architectural planning and governance becomes increasingly crucial for large-scale agile projects (Leffingwell et al., 2008). Due to the existing ambiguity on agile architecture in large-scale agile development, researchers have formulated 12 open research questions on this topic. The first two research questions aim to study the collaboration between architects and agile teams (cf. Dingsøyr et al., 2018c, Britto et al., 2016, Uludağ et al., 2018a) and to analyze the tension between architects with decision-making power and self-organizing agile teams (cf. Dingsøyr et al., 2018c, Uludağ et al., 2019c). Three studies (cf. Dingsøyr and Moe, 2014, Bass, 2019, Martini et al., 2019) mention the issue of managing technical debts as a research question.

4.4.3. Agile planning

Many large agile organizations struggle to implement efficient requirements management processes. Moreover, research on agile planning practices in large organizations is scarce (Heikkilä et al., 2015a, Laanti et al., 2011). The *Agile planning* research stream aims to provide scientific evidence on how large-scale agile projects and organizations perform agile planning activities. We identified four sub-topics in this stream. While a lot of research has covered effort estimation in software development projects (Jorgensen and Shepperd, 2006), little research has been conducted on effort estimation in large-scale distributed projects (Dikert et al., 2016). Thus, the first sub-topic aims to investigate how large-scale agile projects perform effort estimation (cf. Usman et al., 2018). Given the importance of release planning to the success of a development project and the lack of solid empirical evidence in the research of release planning

Table 12

Tabular overview of open research questions for large-scale agile development.

<p>Agile architecture</p> <ol style="list-style-type: none"> 1. How can technical debts be managed and minimized in large-scale agile projects? 2. How is the role of enterprise architects practiced in large-scale agile development? 3. How do architects collaborate with agile teams in large-scale agile development? 4. How can architecture drive large-scale agile transformations? 5. How can the decision-making power between architects and agile teams be balanced? 6. How can software architecture support the coordination of agile teams? 7. How can coordination mechanisms improve architecture sharing at intra- and inter-team level? 8. How can emergent and intentional architecture be balanced? 9. How can the compliance of agile teams with architecture principles automatically determined? 10. What is the effect of applying architecture principles on the outcome of large-scale agile transformations? 11. What are good practices for addressing challenges related to the establishment of architecture principles? 12. Which typical challenges do architects face in large-scale agile development? <p>Agile planning</p> <ol style="list-style-type: none"> 1. How do organizations that have adopted agile methods implement release planning? 2. How do product owners and customers collaborate with developers in large-scale agile projects? 3. What legal limitations exist in contracts that reduce agility in large scale projects? 4. How can technical dependencies between agile teams be minimized? 5. How can the prioritization between functional and non-functional requirements be balanced in large-scale agile projects? 6. What are good contracting models for organizations with external customers? 7. What are typical requirements engineering challenges in large-scale agile development? 8. Which ceremonies can be used to improve the release planning process? 9. What are factors that impact the accuracy of effort estimations in large scale agile projects? 10. How can customer representatives and agile teams be aligned in large-scale agile projects? 11. How can high-level planning elements be incorporated in agile daily routines of large-scale agile projects? <p>Agile portfolio management</p> <ol style="list-style-type: none"> 1. What are best practices in agile portfolio management? 2. How is portfolio management interrelated with other governance functions in an agile context? 3. How can traditional portfolio management techniques be applied in an agile environment? 4. How is the new role of project managers practiced in large-scale agile development? 5. How do agile methods affect program and portfolio management? 6. How to enable the strategic alignment and management of agile project portfolios? 	<p>Agile practices at scale</p> <ol style="list-style-type: none"> 1. What are challenges, benefits, and success factors of scaling agile practices in organizations? 2. What are recurring concerns and good practices of typical stakeholders in large-scale agile development? 3. What are challenges, benefits, and success factors of establishing communities of practice in large-scale agile projects? 4. How can the on-boarding of new agile team members be facilitated in large-scale agile projects? 5. What is the impact of applying agile practices to the overall performance of the organization? 6. What are appropriate metrics to monitor the progress of agile teams and to support transparency in large-scale agile projects? 7. How can agile practices be scaled in organizations from the public sector? 8. How can continuous improvement at intra- and inter-team level be facilitated? 9. Which issues arise when are retrospectives are organized at inter-team level? 10. How can agile practices be adapted to meet inter-organizational needs? <p>Communication and coordination</p> <ol style="list-style-type: none"> 1. How can coordination mechanisms be applied effectively in large-scale agile development? 2. How can effective knowledge networks be created in large-scale agile projects? 3. Which tools can be used to support inter-team coordination in large-scale agile projects? 4. How can the number of meetings in large-scale agile projects be reduced? 5. How can meetings in large-scale projects be designed to increase the effectiveness of coordination? 6. How is intra-team coordination affected by increased focus on inter-team coordination or vice versa? 7. Based from a multi-team perspective, how is coordination in large-scale agile development performed? 8. What are effective organizational structures and collaboration models in large projects? 9. Which effect do cultural differences have on inter-team coordination large-scale agile projects? 10. How can focused work and knowledge be balanced in large-scale agile projects? 11. How does co-location of agile teams affect knowledge sharing in large-scale agile projects? 12. Which challenges are caused by inter-team dependencies within large-scale agile projects? 13. How can daily stand-up meetings be organized in a way that they enable inter-team coordination? <p>Global and distributed software engineering</p> <ol style="list-style-type: none"> 1. What are challenges, benefits, and success factors of applying agile practices in distributed projects? 2. How can virtual agile teams be supported in distributed software development projects? 3. How is knowledge sharing performed in distributed large-scale agile projects? 4. Which human related factors can positively affect globally distributed software projects? 5. How is frequent communication in distributed projects enabled to overcome the challenges of distance? 	<p>Large-scale agile transformations</p> <ol style="list-style-type: none"> 1. What are challenges, benefits, and success factors of performing large-scale agile transformations? 2. How can non-agile units be integrated with agile organizational units to support agile transformations? 3. What are reasons and consequences of conducting large-scale agile transformations on the organizations? 4. How can hierarchical and organizational structures be reduced to facilitate large-scale agile transformation? 5. How are agile structures adopted in business units that are not engaged in IT development or delivery? 6. How can local optimization of agile teams be aligned with the enterprise strategy? 7. Which KPIs exist to measure the enterprise agility? 8. How are agile methods adopted at large-scale in highly regulated environments? 9. How do agile teams adopt common values within large-scale agile transformations? <p>Scaling agile frameworks</p> <ol style="list-style-type: none"> 1. Which scaling agile frameworks are used in organizations and what are their benefits and challenges? 2. How can scaling agile frameworks be selected that are suitable for specific contexts? 3. How is the Scaled Agile Framework adopted in organizations and what are respected challenges and risks when adopting it? 4. How and when should be scaling agile frameworks used in large-scale agile projects? 5. How are scaling agile frameworks tailored to meet the needs of the organizations in which they are adopted? 6. How is the Large-Scale Scrum framework adopted in different types of organizations? 7. Which performance improvements can be observed when adopting scaling agile frameworks? 8. How can agile release trains and value streams be formed in complex organizations? <p>Taxonomy</p> <ol style="list-style-type: none"> 1. How can agile in the large be conceptualized besides the dimension of number of teams? <p>Team autonomy</p> <ol style="list-style-type: none"> 1. How can team autonomy in large-scale agile development be increased? 2. How can inter-team coordination and team autonomy be balanced in large-scale agile projects? 3. What are effective intra- and inter-team coordination mechanisms for autonomous agile teams? 4. How can autonomous teams be designed, supported, and coached? 5. What are barriers to team autonomy in large-scale agile development? 6. How do governance structures influence team autonomy in large-scale agile development?
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in large-scale agile organizations (Heikkilä et al., 2015b), the second sub-topic aims to describe how these organizations perform release planning. Similar to other research streams, the third sub-topic aims to report on challenges and success factors in adopting agile planning practices (cf. Bjarnason et al., 2011b, Alsaqaf et al., 2018, Alsaqaf et al., 2017). While agile methods strongly emphasize customer involvement, companies struggle to meet the needs of customers as very large programs encompass many requirements, stakeholders and developers (Dingsøyr et al., 2012, Olsson et al., 2013). Hence, the last sub-topic aims to reveal how large-scale agile projects can actively involve customers (cf. Olsson et al., 2013, Dingsøyr et al., 2018b, Olsson and Bosch, 2015). Notable results pertaining the *Agile planning* research stream are:

- Observations showing that incorporating agile practices into requirements engineering can overcome existing challenges, e.g., communication gaps and over-scoping, but can also introduce new challenges, e.g., balancing agility and stability and ensuring sufficient competencies in cross-functional teams (see Bjarnason et al., 2011b).
- Observations indicating that the scale of a large-scale agile project, e.g., the number of sites, the number of stakeholders, the size and complexity of the legacy code, and the coordination between different types of stakeholders make estimation and planning very challenging (see Usman et al., 2018).
- A list of ten benefits, e.g., improved communication, transparency, and dependency management, and nine challenges, e.g., lack of preparation and prioritization of requirements, unrealistic schedules, and inadequate architectural planning, when using a release iteration planning method in large-scale agile projects (see Heikkilä et al., 2015b).

We identified 11 research questions for future studies. Although release planning is a critical success factor in agile software projects (Chow and Cao, 2008), there is little research on large-scale agile release planning (Heikkilä et al., 2013). Researchers call for studying how companies that have adopted agile methods implement release planning (cf. Dingsøyr and Moe, 2013, Heikkilä et al., 2010, Heikkilä et al., 2013). They suggest analyzing how companies can use agile ceremonies in the release planning process and how companies can incorporate high-level planning elements into daily routines of large-scale agile projects (cf. Evbota et al., 2016, Bick et al., 2016). As large-scale agile programs often have a large number of stakeholders and users, and their needs have to be communicated to a large number of developers, customer engagement can be a major challenge (Dingsøyr et al., 2018b). Thus, scientists suggest further research on customer-developer collaboration in large-scale agile projects (cf. Dingsøyr and Moe, 2013, Dingsøyr and Moe, 2014). They also call for research on identifying appropriate contracting models for companies with external customers (cf. Bass, 2019) and how companies can facilitate alignment between customer representatives and agile teams in large-scale agile projects (cf. Dingsøyr et al., 2018b). Researchers should examine legal constraints in contracts limiting the agility of large-scale projects (cf. Dingsøyr and Moe, 2013, Dingsøyr and Moe, 2014).

4.4.4. Agile portfolio management

While the concept of portfolio management is not new (Rautiainen et al., 2011) and is established in the traditional project management literature, the iterative nature of agile methods poses new challenges to the current management practice (Stettina and Hörz, 2015), e.g., the need for portfolio management to be able to respond quickly to changes while connecting agile teams to strategy (Horlach et al., 2019). The *Agile portfolio management* research stream deals with the question of how

companies can adapt their traditional portfolio management approaches to agile environments. This stream can be divided into two sub-topics, namely identifying challenges and success factors of agile portfolio management approaches (cf. Rautiainen et al., 2011, Stettina and Hörz, 2015, Sweetman and Conboy, 2018) and creating patterns for agile portfolio management (cf. Horlach et al., 2019). Stettina and Hörz (2015) provide an overview of portfolio management practices of 14 large European companies affected by agile methods and describe the challenges, implications, and benefits of agile methods on portfolio management practices. Horlach et al. (2019) propose four design goals for an effective agile portfolio management and six design principles for achieving these goals. Interesting findings of the *Agile portfolio management* research stream include:

- Observations indicating that implementing a structured portfolio management process can help reduce time-to-market, improve project visibility, and coordinate the work of agile teams (see Rautiainen et al., 2011).
- Observations suggesting that most challenges associated with agile portfolio management are process-related and that an alignment with the customer and involvement of the business is beneficial (see Stettina and Hörz, 2015).
- Formulation of 16 propositions for the effective management of agile projects portfolios, e.g., that portfolio managers need to find the right balance between control and autonomy in agile projects, and that agile project portfolios require mechanisms for simple, fast, and collective decision-making (see Sweetman and Conboy, 2018).

Within the *Agile portfolio management* research stream, we identified six open research questions. As existing best practices for portfolio management are more suited for stable environments (Horlach et al., 2019), two studies (cf. Bass, 2019, Horlach et al., 2019) suggest researchers identifying best practices for agile portfolio management. Hobbs and Petit (2017) suggest further research on the impact of adopting large-scale agile methods on portfolio management. Rautiainen et al. (2011) recommend exploring how companies can apply traditional portfolio management techniques in agile environments.

4.4.5. Agile practices at scale

Adopting and scaling agile practices outside of their ideal context requires rethinking the original underlying assumptions of agile practices (Rolland et al., 2016). The *Agile practices at scale* research stream aims to explore how companies tailor genuine agile practices to fit large-scale projects. We identified eight sub-topics in this research stream. The first sub-topic mainly analyzes how companies tailor Scrum-related roles and artifacts in large projects (cf. Bass, 2016b, 2014, Bass and Haxby, 2019). The next four sub-topics describe the application of different agile and lean practices in large agile projects, namely Kanban (cf. Tripathi et al., 2015), Retrospectives (cf. Dingsøyr et al., 2018a), Community of Practices (cf. Paasivaara and Lassenius, 2014, Šmite et al., 2019a, Šmite et al., 2019b), and Rapid Application Development (cf. Berger and Beynon-Davies, 2009). The sixth sub-topic, like other research streams, deals with identifying challenges and success factors for applying agile practices in large-scale projects (cf. Uludağ and Matthes, 2019, Kalenda et al., 2018, Saeeda et al., 2015). The seventh sub-topic mainly generalizes and conceptualizes observations from case studies in the form of models related to applying agile practices in large-scale projects (cf. Weiss and Brune, 2017, Uludağ et al., 2019e, Schuh et al., 2018). Inspired by existing pattern languages on agile software development, the eighth sub-topic aims to provide best practices for large-scale agile endeavors (cf. Uludağ et al., 2019a, 2018b). Notable findings of the *Agile practices at scale* research stream are:

- Observations showing that adopting agile practices in large-scale projects brings several benefits, e.g., increased control and transparency over the project and better learning and understanding through direct communication, but also raises new issues, e.g., administrative overhead and coordination, and limited focus on architecture (see Petersen and Wohlin, 2009).
- Observations pointing that organizational culture, previous agile experience, and management support are key success factors in scaling agile practices and that resistance to change, an overly aggressive time-frame for adoption, and integration with existing non-agile business processes are critical challenges in scaling agile methods (see Kalenda et al., 2018).
- A study showing that medium and large software projects using agile methods perform better on average than projects using non-agile methods and that agile methods are more likely to succeed compared to traditional methods as project size increases (see Jørgensen, 2018).

The use of agile methods on large-scale projects brings unprecedented challenges (Dingsøyr et al., 2018b). We identified 10 related research questions, of which the unveiling the challenges, benefits, and success factors of scaling agile practices in organizations was the most frequently stated (cf. Laanti et al., 2011, Kalenda et al., 2018, Theobald and Diebold, 2018). Although several pattern languages documenting best practices for agile projects have been published in agile software development research (cf. Beedle et al., 1999; Coplien and Harrison, 2004; Beedle et al., 2010), the body of knowledge about best practices in large-scale agile development is still emerging. Several studies suggest identifying best practices for large-scale agile endeavors (cf. Petersen and Wohlin, 2009, Uludağ et al., 2019a, Kalenda et al., 2018). Given the importance of communities of practices for knowledge sharing, inter-team coordination, and technical work (Larman, 2010, Paasivaara and Lassenius, 2014), several researchers recommend future studies to investigate the challenges, benefits, and success factors of establishing communities of practices in large-scale agile projects (cf. Moe et al., 2016, Bass, 2019, Paasivaara and Lassenius, 2014). Since onboarding newcomers in large-scale agile projects might be challenging (Moe et al., 2016), three studies propose as future work to investigate how companies can facilitate the onboarding process of new agile team members in these projects (cf. Moe et al., 2016, Bass, 2019, Moe et al., 2019b). Several studies suggest identifying metrics to quantify the impact of applying agile practices on overall organizational performance and to monitor the progress of agile teams in large-scale agile projects (cf. Dingsøyr and Moe, 2014, Evbota et al., 2016, Heikkilä et al., 2017).

4.4.6. Communication and coordination

Coordinating work is critical when managing large projects with multiple teams (Moe et al., 2018). This circumstance is also true for large-scale agile projects, as work is performed by many developers and development teams simultaneously, and the frequent and iterative delivery of results requires work and knowledge coordination at different levels (Dingsøyr et al., 2018b; Nyruud and Stray, 2017). Achieving effective coordination in large-scale agile projects is difficult due to the complexity of these projects (Nyruud and Stray, 2017). The *Communication and coordination* research stream tackles the issue of how agile teams can effectively coordinate and communicate with each other. The *Communication and coordination* stream covers multiple topic levels consisting of two sub-topics, namely inter-team coordination and knowledge sharing, and another seven subordinate

sub-topics. Since coordination between teams is critical in managing large-scale endeavors (Dingsøyr et al., 2017), the inter-team coordination sub-topic mainly aims to identify and describe different coordination mechanisms and coordination modes for aligning agile teams (cf. Dingsøyr et al., 2018c, 2017; Nyruud and Stray, 2017). Within the inter-team coordination sub-topic, we identified five additional sub-topics that aim (i) to advance the conceptual understanding of inter-team coordination through the lens of multi-team systems (cf. Scheerer et al., 2014, Bjørnson et al., 2018, Scheerer et al., 2015), (ii) describe different mechanisms and modes for coordinating agile teams (cf. Dingsøyr et al., 2017, Berntzen et al., 2019, Moe et al., 2018), (iii) reveal factors that influence the performance of agile teams (cf. Gustavsson, 2018a, Lindsjörn et al., 2018), (iv) identify challenges and success factors related to the coordination of agile teams (cf. Bick et al., 2018, Nyfjord et al., 2014), and (v) describe the adoption of agile methods beyond organizational boundaries (cf. Figalistic et al., 2019). Since resource availability in a team's knowledge network and the effective knowledge coordination between agile teams become paramount in large-scale agile projects (Šmite et al., 2017), the knowledge sharing sub-topic mainly aims to describe how agile teams can share their knowledge and expertise with other teams. We identified two sub-topics in the knowledge sharing sub-topic that aim to answer the questions on how companies tailor agile practices to enable scaling across different knowledge boundaries (cf. Rolland, 2016) and how companies can build effective knowledge networks in large-scale agile projects (cf. Šablís and Šmite, 2016, Moe et al., 2014, Šmite et al., 2017). Notable results of the *Communication and coordination* research stream are:

- Observations suggesting that the combination of traditional planning at an inter-team level and agile development at a team level leads to ineffective coordination in large-scale agile development, as a lack of dependency awareness is hampered by misaligned planning activities at the team and inter-team levels (see Bick et al., 2018).
- Observations indicating that group mode coordination is central for achieving effective inter-team coordination in large-scale agile projects, using scheduled and unscheduled meetings, e.g., product owner meetings and spontaneous discussions in the open work area (see Šmite et al., 2017).
- Observations pointing that networking is essential in solving complex tasks in large-scale agile projects and that several mechanisms can support the creation of knowledge networks, e.g., introducing formal technical experts and facilitating communities of practice (see Moe et al., 2018).

Due to the high number of articles in the *Communication and coordination* research stream, we identified 13 research questions that were most frequently for a given stream. Because the coordination of many agile teams is a key challenge (Dingsøyr et al., 2018c), several researchers emphasize further research to investigate how companies can design and apply coordination mechanisms for increasing the effectiveness of coordination (cf. Bass, 2016a, Dingsøyr et al., 2018c, Stray, 2018). They also call for research to analyze how companies can reduce the number of meetings in large-scale agile projects (cf. Dingsøyr et al., 2018c, Stray, 2018) and identify tools that companies can use for inter-team coordination (cf. Bass, 2019, Stray et al., 2018, Stray, 2018).

4.4.7. Global and distributed software engineering

Given the benefits to both customer and vendor companies in terms of low cost, early product delivery, and high-quality products, companies are increasingly deploying virtual teams that operating across geographical boundaries to develop software (Niazi

et al., 2016; Olsson et al., 2006). The competitive advantages and business profits of agile methods motivate companies to adopt agile methods in large, globally distributed projects (Shameem et al., 2017). Agile methods are more difficult to scale in distributed projects due to additional challenges, e.g., communication and coordination issues, cultural differences, and temporal issues (Dikert et al., 2016; Paasivaara et al., 2008b). The *Global and distributed software engineering* research stream deals with how companies can use agile methods in large, globally distributed projects. Studies mainly focus on two sub-topics, namely identifying challenges and success factors in adopting agile methods in large, globally distributed projects (cf. Shameem et al., 2018c, 2017; Paasivaara et al., 2008b) and the tailoring of agile methods to meet the needs of these projects (cf. Bass, 2016a,b, 2014). As an example for the first sub-topic, Shameem et al. (2017) describe critical factors that positively impact the adoption of agile methods in large, globally distributed projects based on a systematic literature review. Related to the second sub-topic, Bass (2013) uses 46 interviews with eight companies to investigate how companies adapt the role of the product owner to the needs of large, geographically distributed software projects. Noteworthy findings related to the *Global and distributed software engineering* research stream include:

- A list of 11 challenges identified in large, globally distributed agile projects, of which 6 were evaluated as critical: lack of requirements analysis, customer involvement, communication, roles and responsibilities, management commitments, and knowledge sharing (see Shameem et al., 2018a).
- A classification model for large, globally distributed agile projects contrasting solution focused development and execution focused development (see Bass, 2016b).
- Observations indicating that adopting agile practices based on Scrum in a large, globally distributed agile project helps mitigate the biggest problem of large, globally distributed projects, namely communication, by creating frequent possibilities to communicate across distributed sites, e.g., through Daily Scrum meetings (see Paasivaara et al., 2008b).

We identified five open research questions in the *Global and distributed software engineering* stream. As many companies scale agile methods to distributed environments due to fast development rates and low development costs (Shameem et al., 2018c), identifying challenges, benefits, and success factors when scaling agile to distributed organizations was the most frequently cited research question (cf. Dingsøyr and Moe, 2013; Shameem et al., 2018c; Paasivaara et al., 2008b).

4.4.8. Large-scale agile transformations

Companies are striving to become agile to respond to dynamic environments and sustain their survival. As a result, many companies are extensively introducing agile methods leading to large-scale agile transformations (Gerster et al., 2018; Fuchs and Hess, 2018; Dikert et al., 2016). These transformations entail new managerial challenges, e.g., lack of top management engagement (Fuchs and Hess, 2018), skepticism towards the new way of working (Dikert et al., 2016) or establishing an enterprise-wide agile culture and mindset (Uludağ et al., 2018b). The *Large-scale agile transformations* research stream aims to shed light on how companies undergo these transformations to meet the imperatives of agile companies. We identified three sub-topics in this research stream. Like other streams, the first sub-topic deals with identifying a set of observed success factors and challenges when companies undertake large-scale agile transformations (cf. Laanti et al., 2011; Gerster et al., 2018; Jovanović et al., 2017). As these transformations represent large episodic change processes that have a large impact on the employees (Fuchs and Hess, 2018)

and changing the peoples' mindset is more difficult than teaching new practices (Uludağ et al., 2018b), the second sub-topic discusses various ways in which companies can establish an agile mindset and define common values among employees (cf. Uludağ et al., 2018b; Paasivaara et al., 2014b). The third sub-topic takes a more theoretical stance and aims to theorize the process behind large-scale agile transformations (cf. Carroll and Conboy, 2019). Fuchs and Hess (2018) provide an example for the first sub-topic and captures the interplay of challenges, coping, and scaling actions in the execution of large-scale agile transformations through socio-technical systems theory. Relating to the second sub-topic, Paasivaara et al. (2014b) report how Ericsson established value workshops to align different sites and teams as part of its large-scale agile transformation. Carroll and Conboy (2019) provide an example for the third sub-topic, applying normalization process theory to examine the normalization of these transformations. Notable results of the *Large-scale agile transformations* research stream are:

- A survey indicating that while a large-scale agile transformation poses new challenges, e.g., agile deployment and adaptation of agile methods to fit the organization and requirements management and planning in a flexible and iterative manner, it also brings several benefits, e.g., higher satisfaction, a feeling of effectiveness, and increased transparency and autonomy, which is why most respondents do not want to return to the old way of working (see Laanti et al., 2011).
- A list of 35 challenges, e.g., agile difficult to implement and integrating non-development functions, and 29 success factors, e.g., management support and choosing and customizing the agile model, were reported for large-scale agile transformations (see Dikert et al., 2016).
- Observations stating introducing agile practices in an organization that has been working in a plan-driven way leads to several improvements, e.g., increased release frequency and better reflection of the customers' needs, but also raises several challenges, e.g., support for coordinating a high number of teams and integration of release projects in the overall development process (see Petersen and Wohlin, 2010b).

As the *Large-scale agile transformations* research stream has flourished in recent years, especially in the last two years, several studies formulated important research questions as avenues for future research. The most frequently asked research question aims to identify challenges, benefits, and success factors in conducting large-scale agile transformations (cf. Kettunen and Laanti, 2008; Gerster et al., 2019; Jovanović et al., 2017). As “agile breaks everything” and adopting agile practices may have far-reaching implications for companies (Kulak and Li, 2017; Gerster et al., 2018), several researchers call for examining the reasons for performing large-scale agile transformations and their impact on companies (cf. Bjarnason et al., 2011b; Gerster et al., 2019; Abrar et al., 2019). Since companies often encounter challenges when agile units need to collaborate with non-agile departments (Kulak and Li, 2017), some studies propose to investigate how companies have overcome these challenges from a longitudinal perspective (cf. Barroca et al., 2019a; Gerster et al., 2018, 2019). From an integrational perspective, three studies suggest further research on how companies can adopt agile structures in business units that are not engaged in software development or delivery (cf. Moe and Dingsøyr, 2017; Bass, 2019; Gerster et al., 2019). Hierarchical control and bureaucracy mechanisms can act as barriers for the successful performance of large-scale agile transformations (Karvonen et al., 2018), researchers should explore how companies can dissolve their hierarchical structures to facilitate these transformations (cf. Moe and Dingsøyr, 2017; Bass, 2019; Barroca et al., 2019a).

4.4.9. Scaling agile frameworks

Some custodians of existing agile methods and practitioners have created several scaling frameworks that claim to provide off-the-shelf solutions for solving issues related to the large-scale adoption of agile methods (Uludağ et al., 2021, Dingsøyr et al., 2018b, Carroll and Conboy, 2019). As there is a increasing interest in adopting scaling frameworks from a practical perspective (Digital.ai, 2020), there is also a growing academic interest in studying the adoption of these frameworks within the *Scaling agile frameworks* research stream. We identified eight sub-topics in this stream. As empirical evidence on the adoption of scaling frameworks is still very much in its infancy (Conboy and Carroll, 2019), the first sub-topic aims to highlight challenges and recommendations for companies seeking to adopt scaling frameworks (cf. Conboy and Carroll, 2019). The other six sub-topics mainly analyze how popular scaling frameworks are adopted (cf. Salameh and Bass, 2019, Gustavsson, 2019c, Lal and Clear, 2018). The last sub-topic aims to provide a comparison of these frameworks (cf. Alqudah and Razali, 2016, Theobald et al., 2019, Diebold et al., 2018). Conboy and Carroll (2019) provide an example for the first sub-topic and unveils nine challenges associated with implementing scaling frameworks and a set of recommendations to address these challenges adequately. Relating to the six sub-topics analyzing the adoption of popular frameworks, Salameh and Bass (2019) present a case study of how a large company adapted Spotify practices to promote the effectiveness of team autonomy in a mission-critical project. Lal and Clear (2018) provide another example, presenting a case study on how a global software vendor transitioned to an agile company by adopting DAD. Related to the last sub-topic, Alqudah and Razali (2016) compare six scaling frameworks, e.g., DAD, LeSS, and SAFe, based on various criteria, e.g., team size and available training. Noteworthy results of the *Scaling agile frameworks* research stream are:

- A maturity model consisting of levels, principles, and practices for defining a roadmap for SAFe adoption and assessing the level of adoption (see Turetken et al., 2017).
- A list of nine challenges, e.g., comparing scaling frameworks and top-down vs. bottom-up implementation, and a set of recommendations to overcome these challenges, e.g., using a small number of metrics to compare frameworks and determining whether a framework promotes a top-down or bottom-up implementation approach, when implementing scaling frameworks (see Conboy and Carroll, 2019).
- A survey indicating that the SAFe adoption leads to several benefits, e.g., improved transparency, cooperation, and cadence, but also entails several obstacles, e.g., old mindset and culture, SAFe has not correctly fitted to the organization, and missing fluency when using SAFe (see Laanti and Kettunen, 2019).

The selected studies within the *Scaling agile frameworks* research stream named eight research questions for further investigation by researchers. The most frequently stated research question on scaling agile frameworks deals with the observation of adopting specific scaling frameworks in companies and the associated benefits and challenges (cf. Bass, 2019, Lal and Clear, 2018, Paasivaara et al., 2018). As scaling frameworks are often not selected systematically but merely based on the popularity of the framework or recommendation of consultants, future work should identify contextual factors and comparison criteria that companies can use to select scaling frameworks systematically (cf. Moe et al., 2016, Paasivaara and Lassenius, 2016, Petersen and Wohlin, 2010b). Since many companies also adapt scaling frameworks to their organizations, two studies (cf. Dikert et al., 2016, Paasivaara et al., 2018) call for future research on how companies tailor scaling frameworks to meet their needs. There is also a call for research on the two most widely adopted scaling

frameworks, namely SAFe and LeSS, to study their adoption in companies (cf. Turetken et al., 2017, Uludağ et al., 2019b, Putta et al., 2019).

4.4.10. Taxonomy

The *Taxonomy* research stream deals with providing more conceptual clarity related to large-scale agile development, as well as the scale and implications for scalability of agile methods. Power (2014) explores when scaling approaches are appropriate in large organizations and discusses three contexts for agility at scale. Rolland et al. (2016) take a more theoretical stance to clarify the meaning of large-scale agile development by examining its underlying assumptions in existing studies. Dingsøyr et al. (2014) provide a taxonomy for characterizing large-scale agile projects based on the number of agile teams. Noteworthy results of the *Taxonomy* research stream are:

- Three contexts for agility at scale: (i) being agile in a team inside a large organization, (ii) using agile approaches in a large development effort inside a large organization, (iii) and the large organization being itself agile (see Power, 2014).
- A comparison of 10 prevailing assumptions in existing studies with a set of alternative assumptions better suited to the characteristics of large-scale agile projects, e.g., collective code ownership vs. transferring, translating, and transforming knowledge across boundaries (see Rolland et al., 2016).
- A taxonomy of scale, consisting of three categories: (i) small-scale (1 team), (ii) large-scale (2–9 teams), and very large-scale (≥ 10 teams) (see Dingsøyr et al., 2014).

We identified one research question in the *Taxonomy* stream. Two articles (cf. Rolland et al., 2016, Dingsøyr et al., 2014) suggest further research verifying the current taxonomy of scaling, which is currently merely based on the number of teams involved in large-scale agile projects (Dingsøyr et al., 2014), and identifying other adequate scaling dimensions for classifying the scale of agile development projects.

4.4.11. Team autonomy

In large-scale agile development, the effective functioning of team autonomy is challenged as a certain amount of autonomy has to be sacrificed to reach consensus on common standards and align work with other teams (Mikalsen et al., 2019, Gustavsson, 2019a). The *Team autonomy* research stream is primarily concerned with how complex organizations affect team autonomy and how they can strike a balance between self-organizing teams focused on their own goals and those of the broader organization. We identified two sub-topics in *Team autonomy* stream related to identifying challenges and success factors in establishing team autonomy in large-scale agile endeavors (cf. Moe et al., 2019a, Mikalsen et al., 2019, Gustavsson, 2019a) and in the context of the interplay between governing and autonomizing agile teams (cf. Šablīs and Šmite, 2016, Tendedez et al., 2018, Petit and Marnewick, 2019). For instance, Moe et al. (2019a) analyze large-scale projects and presents barriers that reduce the extent of team autonomy. Concerning the second sub-topic, Šablīs and Šmite (2016) investigate the interplay between governance and team autonomy by identifying governance roles that support teams. Interesting findings related to the *Team autonomy* research stream include:

- Observations indicating that there are two barriers to team autonomy in large-scale agile development: overarching goals that are often set by management without team involvement and organizational dependencies that result in teams having to manage additional tasks (see Moe et al., 2019a).

- Observations suggesting that reliance on resources outside of the large-scale agile program, e.g., shared IT resources, creates external dependencies and reduces the autonomy of agile teams (see Mikalsen et al., 2019).
- A model for assessing the autonomy of agile teams in large-scale agile development (see Petit and Marnewick, 2019).

We identified six research questions in the *Team autonomy* research stream. The most frequently cited research questions relate to how to improve team autonomy in large-scale agile endeavors (cf. Moe and Dingsøyr, 2017, Šāblis and Šmite, 2016, Bick et al., 2018) and how to balance coordination between agile teams and their autonomy in large-scale agile projects (cf. Stray et al., 2018, Šāblis and Šmite, 2016, Dingsøyr et al., 2018b), as the need for coordination and control can restrict a team's autonomy (Šāblis and Šmite, 2016).

5. Discussion

In this section, we discuss our general observations on the start-of-the-art on large-scale agile development.

Reflection on the research of the past 13 years. Since the first publication in 2007, researchers worldwide have lavished attention to study the application of agile methods in large projects and organizations. While the number of published studies started to accelerate in 2013, the academic interest has been steadily growing. The maturation of the research field can be seen both in the increasing number of published studies, as well as in increasing number of articles in top journals. While the 52 included papers from the most prominent systematic literature review on large-scale agile development by Dikert et al. (2016) comprised mostly experience reports indicating a lack of sound academic research, the 136 included studies in this study covered only research papers excluding personal opinion and experience papers from practitioners and scientists signaling a tremendous shift of the scientific foundation of large-scale agile development. We believe that this academic traction is sparked by the omnipresent industrial relevance of the topic demanding scientific assistance by researchers (cf. Dingsøyr et al., 2019, Dikert et al., 2016). While almost 60% of the papers represent case studies mainly being exploratory and less theoretical, they do not pay enough attention to establish theoretical underpinnings as similar to studies on agile software development (Dingsøyr et al., 2012). Analogous to agile software development and agreeing with Dingsøyr et al. (2012), we believe that the area of large-scale agile development can mature as a research discipline only if adequate efforts are made to provide a solid theoretical scaffold.

Current structure of the research landscape. Research on large-scale agile development has been conducted mainly empirically and qualitatively to describe and explain how companies adopt large-scale agile methods. Consequently, extant research has been dominated by evaluation research assessing the large-scale adoption of agile methods and deriving a set of lessons learned instead of creating solution artifacts in the form of models, frameworks/methods, and tools. Like Batra (2020), we can further observe an apparent lack of quantitative studies using surveys as data collection instruments to provide quantitative investigations and assessments, e.g., quantitatively assessing the strengths and weaknesses of scaling frameworks or performance of agile teams in large agile multi-team settings.

Outlook for future research undertakings. We encountered some intriguing observations, which is why we believe that large-scale agile development will continue to be a relevant topic in practice as well as in academia. An analysis of the past State of Agile surveys conducted by Digital.ai (cf. Digital.ai (2018, 2019, 2020)) reveals an ever-increasing adoption of agile methods in

organizations, including the adoption of scaling agile frameworks. According to Digital.ai (2020), this trend will likely continue and also intensify, especially concerning the more significant expansion and scaling of agile methods beyond software development, namely across the whole company. Parallel to this development, the number of scaling agile frameworks proposed by software practitioners is still flourishing and likely to further grow as the creators of these frameworks feel committed to develop their frameworks further (Uludağ et al., 2021). The number of published studies in the last years (see Section 4.2) and the increasing interest of various publication venues (see Table A.1) from different research domains (see Fig. 17) indicate that the growing industrial interest in large-scale agile development is backed by a growing scientific interest across diverse research communities. Although researchers made considerable efforts to close research gaps in various research streams of large-scale agile development, a high number of open research questions (see Table 12) are still waiting to be addressed by researchers.

Contemplation of the current phenomenon. Although the early advice from the agile community was that scaling agile methods to larger projects and organizations is “*probably the last thing anyone would want to do*” (Reifer et al., 2003), and the advice from several fields is to reduce the size of software projects as much as possible (Andriole, 2017), why are companies still trying to adopt agile methods outside of their sweet spot in larger projects and organizations? One plausible explanation is that solutions often demand too much work for a single team, or that new solutions are so complex or so dependent on existing systems that it is considered inefficient or impractical to split the development efforts into small projects, making agile methods a way to reduce risk at scale while also facilitating innovation (Dingsøyr et al., 2019). Despite the challenges of large-scale adoption of agile methods, we observe that the idea permeates almost every continent and industry sector. We revealed more than 150 companies distributed over the globe across various sectors make the use of agile methods in larger projects and organizations (see Section 4.1.1). Our findings and the survey results of Digital.ai (2020) indicate that, regardless of their organizational size, companies are adopting agile methods at scale. However, our results show that most of the adopting companies have more than 5000 employees, accounting for almost 70% of all identified case companies with stated size, indicating that this phenomenon is probably more relevant for large companies than for small companies.

New emerging research themes. Early research on large-scale agile development started with contributions related to the *Agile practices at scale*, *Global and distributed software engineering*, and *Scaling agile frameworks* research streams (see Section 4.4.1). Themes recently receiving more focus include *team autonomy* and *large-scale agile transformations*. For instance, as large-scale agile transformations can be characterized as episodic organizational change processes (Fuchs and Hess, 2018), there is a need to conduct longitudinal case studies that accompany these transformations to investigate their long-lasting effects.

6. Threats to validity

Although we employed a rigorous study design and paid particular attention to the selection and analysis of published studies, our study has some limitations. The results of this systematic mapping study may be affected by various threats to validity, which are (i) study search incompleteness, (ii) study selection bias, (iii) study distribution imbalance, and (iv) data extraction inaccuracy, which we will discuss in the following.

6.1. Incompleteness of study search

There may be some relevant publications that we did not retrieve by our search, which may affect the completeness of

our study. To mitigate this risk, we searched the most common electronic databases in which a large number of journals as well as conference and workshop proceedings in the fields of software engineering and information systems are indexed. We also performed a preliminary search before the main search to improve the correctness and completeness of the search results. These measures reduced the probability of missing relevant studies.

6.2. Bias on study selection

The selection of relevant studies largely depends on the personal knowledge of the researchers, which may lead to a bias in the results of the study selection. To mitigate this bias, we created a set of selection criteria (see Section 3.2.2). As the researchers of this study may have different understandings of the selection criteria, we conducted a preliminary search before the main search to ensure that the researchers had a consistent understanding of the selection criteria. Two reviewers also performed the study selection process in parallel and independently and then discussed and resolved any conflicts between their results to mitigate personal bias in study selection. A potential bias may arise from excluding the grey literature, e.g., white papers, technical reports, or editorials. This potential bias is inherent to our study design and did not significantly impact our study. We wanted to focus exclusively on state of the art presented in high-quality scientific papers that have undergone rigorous peer-reviewed publication processes.

6.3. Imbalance of study distribution

Around one-third of the selected publications come from the proceedings of the International Conference on Agile Software Development and International Workshop on Large-Scale Agile Development (see Appendix A). These studies may, to some extent, carry the bias of conference and workshop organizers and committee members. However, we did not address this type of bias as there is no effective way to determine whether such bias exists. Hence, we were not able to mitigate this kind of bias. Moreover, conferences and workshops, by definition, allow the publication of immature results that may distort the level of evidence of the selected studies.

6.4. Inaccuracy of data extraction

Data extraction bias may negatively affect the accuracy of data extraction results, affecting the classification results of the selected publications. Two researchers specified a list of extracted data items to mitigate this risk and reduce possible misunderstandings on the data items to be extracted. Two researchers also performed a pilot data extraction process before the formal data extraction. Further, two researchers conducted the main data extraction process in parallel and independently. Two researchers discussed and resolved conflicts arising from the data extraction results in several workshop sessions.

7. Conclusions and future work

Large-scale agile development is on the verge of becoming a mature research area, as many publications on large-scale agile development have appeared in scientific conferences and journals, leading to a growing body of knowledge. However, until now, no systematic mapping study has been published that systematically identifies, analyzes, and classifies the state of research. This mapping study aims to fill this gap and provide an overview of the research activities in large-scale agile development. Based on this objective, we selected 136 studies as a result of the systematic mapping process.

Our findings show that the adoption of agile methods has indeed inspired large companies around the world and in various sectors to apply these methods to larger projects and organizations. Our results suggest that this industrial interest has sparked significant academic interest in the topic of large-scale agile development, as a total of 136 articles were published in 46 publication venues by more than 200 authors worldwide between 2007 and 2019. In addition, our results show that research on large-scale agile development is mainly empirical and observational rather than solution-oriented, as most studies contribute in the form of lessons learned through case studies. Our results reveal that 10 research streams have emerged over time that focus on different aspects of large-scale agile development, e.g., agile architecture, scaling agile frameworks or team autonomy. Our findings show that the identified research streams raise many open research questions.

We hope that this mapping study will serve as a starting point for new research efforts that address previously neglected or emerging research topics and assist practitioners in the field of large-scale agile development. Based on our findings, we suggest that future research endeavors should pay greater attention to building a solid theoretical scaffold for the observed phenomena in large-scale agile development and should create rigorously developed frameworks, methods, and tools to meet practitioners' needs. Moreover, we recommend researchers to provide more conceptual clarity on the meaning of large-scale agile development, which has not received much attention but plays a crucial role in advancing the research field. We encourage researchers to use the compiled research questions to address the still open research gaps.

CRediT authorship contribution statement

Ömer Uludağ: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Pascal Philipp:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Visualization. **Abheeshta Putta:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft. **Maria Paasivaara:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Supervision. **Casper Lassenius:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Supervision. **Florian Matthes:** Conceptualization, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Distribution of selected studies by publication channels

See Table A.1.

Appendix B. Systematic map overview

See Table B.1.

Table A.1

#	Publication source	Type	Domain	No.	%
1	International Conference on Agile Software Development	Conference	Software engineering	21	15.44
2	International Workshop on Large-Scale Agile Development	Workshop	Software engineering	20	14.71
3	International Conference on Global Software Engineering	Conference	Software engineering	9	6.62
4	IEEE Software	Journal	Software engineering	6	4.41
5	Information and Software Technology	Journal	Software engineering	6	4.41
6	International Workshop on Autonomous Teams	Workshop	Software engineering	6	4.41
7	Empirical Software Engineering	Journal	Software engineering	5	3.68
8	Hawaii International Conference on System Sciences	Conference	Information systems	5	3.68
9	Americas Conference on Information Systems	Conference	Information systems	4	2.94
10	Journal of Systems and Software	Journal	Software engineering	4	2.94
11	Euromicro Conference on Software Engineering and Advanced Applications	Conference	Software engineering	3	2.21
12	International Conference on Enterprise Distributed Object Computing	Conference	Enterprise computing	3	2.21
13	International Symposium on Empirical Software Engineering and Measurement	Conference	Software engineering	3	2.21
14	Journal of Software: Evolution and Process	Journal	Software engineering	3	2.21
15	Project Management Journal	Journal	Project management	3	2.21
16	European Conference on Information Systems	Conference	Information systems	2	1.47
17	International Conference on Information Systems	Conference	Information systems	2	1.47
18	International Conference on Product-Focused Software Process Improvement	Conference	Software engineering	2	1.47
19	Software Process: Improvement and Practice	Journal	Software engineering	2	1.47
20	Bled eConference	Conference	Multidisciplinary	1	0.74
21	CIRP Design Conference	Conference	Multidisciplinary	1	0.74
22	European Conference on Pattern Languages of Programs	Conference	Multidisciplinary	1	0.74
23	Human Computer Interaction	Journal	Human computer interaction	1	0.74
24	IEEE Access	Journal	Multidisciplinary	1	0.74
25	IEEE Transactions on Software engineering	Journal	Software engineering	1	0.74
26	Information Systems Journal	Journal	Information systems	1	0.74
27	International Conference on Advanced Information Systems Engineering	Conference	Information systems	1	0.74
28	International Conference on Computing Communication and Automation	Conference	Multidisciplinary	1	0.74
29	International Conference on Information Systems Development	Conference	Information systems	1	0.74
30	International Conference on Pattern Languages of Programs	Conference	Multidisciplinary	1	0.74
31	International Conference on Perspectives in Business Informatics Research	Conference	Information systems	1	0.74
32	International Conference on Strategic Innovative Marketing	Conference	Marketing	1	0.74
33	International Journal of Information Systems and Project Management	Journal	Information systems	1	0.74
34	International Journal of Advanced Computer Science and Applications	Journal	Multidisciplinary	1	0.74
35	International Journal of Project Management	Journal	Project management	1	0.74
36	International Journal on Advanced Science, Engineering and Information Technology	Journal	Multidisciplinary	1	0.74
37	International Requirements Engineering Conference	Conference	Software engineering	1	0.74
38	International Research Workshop on IT Project Management	Workshop	IT project management	1	0.74
39	International Systems and Software Product Line Conference	Conference	Software engineering	1	0.74
40	International Working Conference on Requirements Engineering	Conference	Software engineering	1	0.74
41	International Workshop on Evidential Assessment of Software Technologies	Workshop	Software engineering	1	0.74
42	International Workshop on Requirements Engineering in Agile Development	Workshop	Software engineering	1	0.74
43	Malaysian Software Engineering Conference	Conference	Software engineering	1	0.74
44	Procedia Computer Science	Journal	Multidisciplinary	1	0.74
45	Software Quality Professional	Journal	Software engineering	1	0.74
46	Workshop on Agile Requirements Engineering	Workshop	Software engineering	1	0.74
Total				136	100

Table B.1

Study	Publication type	Research type	Research approach	Contribution type	Research data type
Petersen and Wohlin (2009)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Laanti et al. (2011)	Journal	Evaluation research	Survey	Lessons learned	Primary study
Paasivaara and Lassenius (2014)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Gerster et al. (2018)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Bjarnason et al. (2011b)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Qumer and Henderson-Sellers (2008)	Journal	Solution proposal	Design & creation	Framework/Method	Primary study
Power (2014)	Workshop	Philosophical papers	Case study	Model	Primary study
Heikkilä et al. (2010)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Alqudah and Razali (2016)	Journal	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Shameem et al. (2018a)	Conference	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Duijs et al. (2018)	Conference	Philosophical papers	Case study	Model	Primary study
Salameh and Bass (2019)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Paasivaara (2017)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Bass (2013)	Conference	Evaluation research	Grounded theory	Lessons learned	Primary study
Horlach et al. (2019)	Conference	Solution proposal	Design & creation	Guideline	Primary study
Šablīs and Šmite (2016)	Workshop	Evaluation research	Mixed methods	Lessons learned	Primary study
Theobald et al. (2019)	Workshop	Evaluation research	(Systematic) literature review	Lessons learned	Primary study
Bass (2016a)	Journal	Philosophical papers	Grounded theory	Theory	Primary study
Turetken et al. (2017)	Journal	Solution proposal	Design & creation	Framework/Method	Primary study
Gustavsson (2017)	Workshop	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study

(continued on next page)

Table B.1 (continued).

Study	Publication type	Research type	Research approach	Contribution type	Research data type
Fuchs and Hess (2018)	Conference	Philosophical papers	Case study	Model	Primary study
Dikert et al. (2016)	Journal	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Moe et al. (2019a)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Kettunen and Laanti (2008)	Journal	Solution proposal	Not stated	Framework/Method	Primary study
Martini et al. (2013)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Eybota et al. (2016)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Heikkilä et al. (2013)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Dingsøyr et al. (2018c)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Bick et al. (2018)	Journal	Evaluation research	Grounded theory	Guideline	Primary study
Scheerer et al. (2014)	Conference	Philosophical papers	(Systematic) literature review	Lessons learned	Primary study
Dingsøyr et al. (2017)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Weiss and Brune (2017)	Conference	Solution proposal	Case study	Model	Primary study
Olsson et al. (2013)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Paasivaara et al. (2008a)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Uludağ et al. (2019a)	Conference	Solution proposal	Design & creation	Framework/Method	Primary study
Gustavsson (2019c)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Usman et al. (2018)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Paasivaara and Lassenius (2019)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Gundelsby (2018)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Lal and Clear (2018)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Uludağ et al. (2019e)	Conference	Solution proposal	Mixed methods	Framework/Method	Primary study
Paasivaara et al. (2012a)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Dingsøyr et al. (2018b)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Santos et al. (2015)	Journal	Philosophical papers	Grounded theory	Model	Primary study
Gerster et al. (2019)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Uludağ et al. (2018b)	Conference	Solution proposal	Design & creation	Framework/Method	Primary study
Uludağ and Matthes (2019)	Conference	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Gustavsson (2018a)	Conference	Evaluation research	Survey	Lessons learned	Primary study
Conboy and Carroll (2019)	Journal	Evaluation research	Not stated	Guideline	Primary study
Paasivaara et al. (2013)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Bick et al. (2016)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Bjørnson et al. (2018)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Paasivaara et al. (2012b)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Nyrud and Stray (2017)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Uludağ et al. (2019b)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Uludağ et al. (2019f)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Uludağ et al. (2017)	Conference	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Lindsjørn et al. (2018)	Conference	Evaluation research	Survey	Lessons learned	Primary study
Bjørnson and Vestues (2016)	Workshop	Evaluation research	Not stated	Lessons learned	Primary study
Paasivaara et al. (2018)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Bass (2016b)	Workshop	Solution proposal	Grounded Theory	Model	Primary study
Dingsøyr et al. (2018a)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Heikkilä et al. (2017)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Martini et al. (2019)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Abrar et al. (2019)	Journal	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Papadopoulos (2015)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Moe et al. (2014)	Conference	Evaluation research	Mixed methods	Lessons learned	Primary study
Heikkilä et al. (2015b)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Badampudi et al. (2013)	Conference	Evaluation research	Grounded theory	Lessons learned	Primary study
Stray (2018)	Workshop	Solution proposal	Case study	Theory	Primary study
Gustavsson (2018b)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Shameem et al. (2018c)	Journal	Evaluation research	Mixed methods	Lessons learned	Primary study
Rolland et al. (2016)	Conference	Philosophical papers	Mixed methods	Model	Primary study
Færgi and Moe (2015)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Jørgensen (2019)	Journal	Evaluation research	Survey	Lessons learned	Primary study
Rolland (2016)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Diebold et al. (2018)	Workshop	Evaluation research	Not stated	Guideline	Primary study
Kalenda et al. (2018)	Journal	Evaluation research	Mixed methods	Lessons learned	Primary study
Paasivaara and Lassenius (2016)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Bass (2014)	Conference	Evaluation research	Grounded theory	Lessons learned	Primary study
Britto et al. (2016)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Tendedez et al. (2018)	Journal	Evaluation research	Mixed methods	Lessons learned	Primary study
Šmite et al. (2017)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Šmite et al. (2019a)	Journal	Evaluation research	Mixed methods	Guideline	Primary study
Berntzen et al. (2019)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Paasivaara et al. (2014b)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Uludağ et al. (2018a)	Conference	Solution proposal	Case study	Framework/Method	Primary study
Rautiainen et al. (2011)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Shameem et al. (2017)	Workshop	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Bass and Haxby (2019)	Journal	Evaluation research	Grounded theory	Lessons learned	Primary study
Sekitoleko et al. (2014)	Conference	Evaluation research	Case study	Guideline	Primary study
Petersen and Wohlin (2010b)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Scheerer et al. (2015)	Conference	Philosophical papers	Theoretical	Lessons learned	Primary study
Lagerberg et al. (2013)	Conference	Evaluation research	Case study	Lessons learned	Primary study

(continued on next page)

Table B.1 (continued).

Study	Publication type	Research type	Research approach	Contribution type	Research data type
Pries-Heje and Krohn (2017)	Workshop	Evaluation research	Action research	Lessons learned	Primary study
Berger and Beynon-Davies (2009)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Moe et al. (2018)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Olsson and Bosch (2015)	Workshop	Philosophical papers	Case study	Model	Primary study
Paasivaara et al. (2014a)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Jovanović et al. (2017)	Journal	Solution proposal	Grounded Theory	Theory	Primary study
Alsaqaf et al. (2018)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Thummadi et al. (2017)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Paasivaara et al. (2008b)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Uludağ et al. (2019c)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Dingsøyr et al. (2014)	Conference	Philosophical papers	Not stated	Model	Primary study
Uludağ et al. (2019d)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Martini et al. (2015)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Ozkan and Tarhan (2019)	Journal	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Mikalsen et al. (2019)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Nord et al. (2014b)	Workshop	Solution proposal	Not stated	Guideline	Primary study
Hobbs and Petit (2017)	Journal	Evaluation research	Mixed methods	Lessons learned	Primary study
Stettina and Hörz (2015)	Journal	Evaluation research	Case study	Lessons learned	Primary study
Carroll and Conboy (2019)	Workshop	Philosophical papers	Theoretical	Theory	Primary study
Lindsjörn and Moustafa (2018)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Gustavsson (2019b)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Gustavsson (2019a)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Nyffjord et al. (2014)	Workshop	Solution proposal	Design & creation	Guideline	Primary study
Šmite et al. (2019b)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Jørgensen (2018)	Conference	Evaluation research	Survey	Lessons learned	Primary study
Petit and Marnewick (2019)	Workshop	Evaluation research	Case study	Lessons learned	Primary study
Barroca et al. (2019b)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Karvonen et al. (2018)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Kettunen et al. (2019)	Workshop	Evaluation research	Survey	Lessons learned	Primary study
Putta et al. (2019)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Theobald and Diebold (2018)	Conference	Evaluation research	Mixed methods	Lessons learned	Primary study
Tessem and Maurer (2007)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Sweetman and Conboy (2018)	Journal	Evaluation research	Theoretical	Guideline	Primary study
Stettina and Schoemaker (2018)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Laanti and Kettunen (2019)	Workshop	Evaluation research	Survey	Lessons learned	Primary study
Figalst et al. (2019)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Tripathi et al. (2015)	Conference	Evaluation research	Case study	Lessons learned	Primary study
Putta et al. (2018)	Conference	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Schuh et al. (2018)	Conference	Evaluation research	Not stated	Framework/Method	Primary study
Alsaqaf et al. (2017)	Conference	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Saeeda et al. (2015)	Journal	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study
Ravazi and Ahmad (2014)	Conference	Evaluation research	(Systematic) literature review	Lessons learned	Secondary study

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