Towards a Theory on Architecting for Continuous Deployment

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Context: As the adoption of continuous delivery practices increases in software organizations, different scenarios struggle to make it scale for their products in a long-term evolution. This study looks at the concrete software architecture as a relevant factor for successfully achieving continuous delivery goals. Objective: This study aims to understand how the design of software architectures impacts on the continuous deployment of their software product. Method: We conducted a systematic literature review to identify proper evidence regarding the research objective. We exploit two search strategies to identify relevant sources. We analyzed the selected sources adopting a synthesis and analysis approach based on Grounded Theory. Results: Through a systematic literature review, we selected 14 primary sources describing elements of concrete architectures that support continuous deployment. Through our analysis process, we developed a theory that explains the phenomenon of Architecting for Continuous Deployment. The theory describes three other phenomena that provide support for Architecting for Continuous Deployment: Supporting Operations, Continuous Evolution, and Improving Deployability. Furthermore, the theory is composed of the following elements: contexts, actions and interactions (strategies, practices, techniques, design patterns), quality attributes, principles, and effects. We instantiated these elements and identified their interrelationships. The theory is supported by providing bi-directional traceability from the selected sources to the elements and vice-versa. Conclusions: Developing adequate architecture plays a crucial role in enabling continuous delivery. Supporting operations becomes vital to increase the deployability and monitorability of software architecture. These two outcomes require that developers accept responsibility for maintaining the operations. The continuous evolution of the architecture is essential, but it must consider balanced management of technical debt. Finally, improving deployability requires attention to the test strategy and how it affects downtime to enable efficient pipelines.

CCS Concepts: • Software and its engineering → Software architectures; Agile software development.

Additional Key Words and Phrases: Delivery Capability, Continuous Deployment, Systematic Literature Review, Grounded Theory

1 INTRODUCTION

Organizations developing software-intensive solutions that involve innovation or meaningful time-to-market constraints must continuously adapt to untimely changes so they can achieve business goals in the face of a dynamic and competitive market. In this scenario, organizations need to adopt software practices enabling the capacity to deliver new features that can be readily available to end-users. Continuous Software Engineering (CSE) is the umbrella term referring to this set of practices [7] [20].

In principle, several organizations report the benefits of adopting the CSE paradigm. These reported benefits include reduced cycle time, increased reliability productivity, and efficiency [34]. However, the enumerated benefits are not pervasive as others also report challenges when adopting CSE practices, such as increased effort on testing [14, 34, 37, 44], or increased software failure rate [14, 38]. Furthermore, we argue that most research has dealt with the interplay between operations and development [53, 56] or has focused on the development tools and deployment pipelines that are needed to support CSE [47]. A few of these works have highlighted the importance the concrete architecture has on enabling continuous deployment. For instance, [44] mentions that flexible product design is a factor for continuous
delivery. Similarly, a result of [32], suggests that some architectures might not be suitable for Continuous Delivery or Deployment (CD). We claim that not enough attention has been paid on designing and developing a software architecture that can support the continuous delivery of its software product.

This research aims at building a theoretical model of the issues relating to software architecture (including its evolution, decay, and technical debt) and its capacity to support the continuous delivery of the software product. To achieve this, we carried out a systematic literature review (SLR) [30]. The SLR guided the identification of the available evidence. We adopted a qualitative analysis process based on Grounded Theory (GT) procedures to support the analysis and synthesis of the scientific evidence [25]. As a secondary study, we did not follow a whole GT process. Instead, we used GT procedure to support the qualitative synthesis [17] of the evidence revealed by the SLR.

We identified 14 primary resources that provided evidence about how concrete software architectures affect the capacity to deliver software frequently. As a result of the qualitative analysis process, we developed a preliminary theory that describes the phenomenon of architecting for continuous delivery. It also includes three supporting phenomena that arise when looking at designing and supporting such an architecture. In short, the theory describes the following four phenomena: (1) Architecting for continuous deployment, this is the core phenomenon of the theory. This phenomenon deals primarily with software design concerns, but it also describes the context, symptoms to ensure the continuous delivery of valuable software; (2) Supporting operations, which deals with the software developers’ capacity to improve the systems’ monitorability and deployability; (3) Continuous evolution, which deals with increasing the ability to deliver software frequently while avoiding cost overruns. And it strikes a balance between the need to deliver software regularly and the management of technical debt; (4) Improving deployability, which deals with developing efficient pipelines that minimize system downtime. Improving deployability stress the impact that a test strategy has in reducing system downtime.

This paper describes a paradigm and a theory instantiated from it by identifying the elements influencing the aforementioned phenomena. We support their evidence-based nature by providing bi-directional traceability between the elements and their sources. We claim that, while the paradigm and the theory might still offer a partial and preliminary picture of all the concepts associated with architecting for continuous delivery, the results presented in this paper are rich enough to provide explanations, articulate hypotheses, and support further research.

2 BACKGROUND

The software industry has shown an increasing interest and adoption for practices establishing a more continuous flow for the software lifecycle, taking into account the need for change on how software has been conceived, developed, and maintained over the last years. Such interest and adoption are especially true in the context of uncertainty and technological innovation. This new thinking regarding the software lifecycle has been named CSE [7, 20] as it includes practices requiring more constant pacing when performed. Besides, it is rooted in agile practices such as short iterations, which fostered rapid releases and made substantial use of automation, mainly in software build and testing activities. Such automation usually happens in the context of Continuous Integration (CI) practice [4]. With the perceived agility brought by the use of CI, the automated deployment appears as to be an additional step. This way, after successfully executing tests, it makes the application available, in a functional state, and configured into another environment, staging or production. This extension is called Continuous Delivery or Deployment (CD) [26].

In this context, methods and practices supporting software development and operations, along with supporting tools, are proposed and released in the market (by industry or academia) aiming at making the achievement of CSE goals easier, particularly w.r.t. time to deliver software products and services [7]. However, several technologies have
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neither proven their effectiveness or efficiency in providing the intended or claimed benefits nor known limitations associated with their continuous use. Additionally, there is not enough evidence to support decision making in the organizations on the adequacy of such technologies to their contexts. It may cause the failure of introducing them to improve processes concerning delivery velocity, changeability, and the improvement of product or service quality. Some challenges associated with the introduction of such practices include:

- Increase effort on testing activities, including test automation, to keep up with constants changes [14, 34, 37, 38, 40, 44];
- Increase of the software failure rate for not having enough time to plan and execute efficient tests [14, 38];
- Increase of the architectural decay during continuous software evolution [43];
- Growth of Technical Debt (TD) due to reduced time for planning the implementation of change requests [37];
- The domain in which a company operates (telecommunications, embedded systems, games, and others) may impose restrictions on rapid release practices [34, 44];
- Software teams resistance to changes required when adopting rapid release processes [34, 44];
- Customers unwillingness to deal with frequent releases [14, 37, 44].

Particularly, in this study, we are concerned with issues related to software architecture, including its evolution, decay and TD, on the use of rapid release practices, which may impact directly on the delivery capability. In this sense, Rodríguez et al. [44] identified in a systematic review ten groups of factors contributing to the adoption of continuous deployment, which includes flexible product design and architecture as a success factor. Similarly, Laukkanen et al. [32] identified problems, causes and solutions related to system architectural design in the context of a systematic mapping concerning the adoption of CD. These include system modularization, unsuitable architecture, internal dependencies, database schema changes. Although both secondary studies agree on software architecture and design as one important success factor for CD, they do not provide further explanation on how these concepts are articulated to improve chances of succeeding in CD initiatives.

Delivery and deployment capability are represented by the minimum frequencies (time) at which software teams can deliver or deploy software artifacts [36]. In this sense, two frequency metrics can be used: (1) the actual releasable software cycle, which represents the cycle a development team takes to produce an artifact that could be released, but factors out of control of the team prevent such release; and (2) the actual release cycle means how often the software artifact is actually released. We are particularly interested in the first given perspective and how the software architecture contributes to increase such capability.

Regarding primary studies, Bosch and Eklund [8] discuss architectural implications for continuous experimentation. The authors explore concepts related to continuous evolution and experimentation of embedded systems through a case study in the automotive industry. In different domains, Bellomo and colleagues [6] investigated, through an approach based on GT, factors enabling rapid releases. The results show the combination of architecture-related and regular agile practices to balance development speed and product stability.

Usually, the association of software architecture and CSE (more specifically DevOps) ends up with the recommendation of adopting Microservices or Serverless architecture styles. However, we understand these technologies are no silver bullets. After conducting an empirical study, Shahin et al. [49] proposed a conceptual framework to support the process of architecting for CD. Additionally, they also characterize the principle of “small and independent deployment units”, which is a more abstract expression of the previously mentioned architecture styles. It represents a concrete direction for

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the relationship between software architecture and CSE, but we understand further investigation is required, including a broader view of this phenomenon.

3 RESEARCH METHOD

The main goal of this study is to capture and synthesize evidence from the literature targeting the development of a theory to describe how delivery capability is affected by elements of the software architecture in the context of CD practices. The goal does not necessarily aim at achieving a general theory on this topic, as the achievement of such a goal is dependent on the depth of the existing evidence. Rather, we need a first attempt to synthesize such evidence and to direct efforts on missing empirical results. Therefore, to achieve the goal of this research, we have commissioned a Systematic Literature Review [30]. An SLR synthesizing scientific evidence from the literature can drive the building of a theory as stated in the research goal. A systematic mapping study (SMS) would not be enough to achieve this goal, as SMS are structured towards organizing a research area, while our goal requires in-depth synthesis and analysis. We purposefully exclude gray literature since it is difficult to obtain systematic and unbiased evidence from it. Furthermore, as an inclusion criteria (see Section 3.3), we convey how we are interested only in empirical studies, preferably occurring in real settings.

To analyse and synthesize the scientific evidence, we followed a qualitative analysis process based on Grounded Theory [25]. The suggestion and use of GT as a method for qualitative synthesis of SLR outcomes is recognized outside Software Engineering [17, 19]. Besides, it is reinforced in the SE [18] and Information Systems [55] literature. Several secondary studies in SE have applied GT as a synthesis method [1, 21]. Differently from these works, which focused mainly on categorization, our synthesis also follows a theoretical structure, formalized as an adaptation of the paradigm proposed in [51]. We have made available the research protocol in [16].

3.1 Research Questions

The main research question for this study is "Which architectural characteristics contribute to the delivery capability?" Additionally, we breakdown this idea into four secondary questions:

RQ1 What are the variables concerning the concrete architecture influencing the delivery capability?
RQ2 How does the quality of the concrete architecture impact the delivery capability?
RQ3 How do these variables relate to each other to contribute to the delivery capability?
RQ4 How does the effect of the identified variables evolve over time?

3.2 Search Process and Strategy

We performed an automated search in the main used libraries in Software Engineering: Scopus, IEEEXplore, and Web of Science. Also, we complemented this search with a Snowballing process [54]. Following the results of an ad-hoc literature review (summarized in Section 2), we calibrated the candidate search string using three references as control papers [6, 8, 49]. The resulting string was:

("continuous evol" OR "continuous architecting" OR "continuous software evolution" OR "continuous delivery" OR "continuous deployment" OR "continuous integration" OR "continuous software engineering" OR "rapid releases" OR "rapid fielding") AND ("software architecture" OR "software design" OR "architectural design")

1We decided not to use ACM Digital Library, due to its well-documented reproducibility issues [24].
Regarding the snowballing process, we followed the guidelines in [54], applying both backward and forward snowballing. The supporting tools are the same search engines from the automated search. Inclusion/Exclusion criteria for sources identified through Snowballing are also the same as for the automated search strategy (see Section 3.3). Seeds for the snowballing process are the output of the automated search process (after the data extraction phase). Before initiating the snowballing process, the seeds set should be checked against the criteria detailed in the snowballing guidelines (diversity of the community of practice, the size of the seed set, diversity of authors and publishers).

### 3.3 Inclusion and Exclusion Criteria

Inclusion (I) and exclusion (E) criteria follow the research interest on architectural practices supporting CD. Thus, we defined the following criteria:

- **I1** Discuss continuous delivery.
- **I2** Discuss the software system’s architecture within the CD in terms of its variables.
- **I3** Present an empirical/experimental study or experience report with observations in the context of CD.
- **E1** Gray literature.
- **E2** Papers not written in English.
- **E3** The same study reported twice, only the most complete report will be considered.
- **E4** Paper presenting no empirical/experimental evidence (only proposal or position papers).
- **E5** Papers discussing the architecture of the deployment pipeline, including its testing harness.

### 3.4 Selection Procedure

We followed the same selection procedure for both the automated and the snowballing search. All authors participated as reviewers equally. To calibrate our interpretation of the criteria, we adopted an iterative process for the search string development. With the resulting search string, we selected 10 sources to be reviewed and the application of I/E criteria by each researcher discussed. The resulting set of papers was divided into thirds. Each researcher reviewed two-thirds of the papers. The selection process will be guided by Table 1 (adapted from [42]). Papers classified as F will be excluded. Papers classified as C and D will be read in full to justify inclusion/exclusion.

### 3.5 Data Extraction

Table 2 presents the data extraction form developed to answer our research questions.

### 3.6 Quality Appraisal Criteria

We derived our quality criteria (Table 3) based on [45] and [31], so that we included a more qualitative set of criteria for evaluating quality and a more experimental set, respectively.

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Table 2. Information Extraction Form

| Field                                      | Description                                                                 | Related RQ |
|--------------------------------------------|-----------------------------------------------------------------------------|------------|
| Bibliographic information                  | Title, authors, abstract, publication venue and date.                      | N/A        |
| Variables and quality metrics influencing delivery capability | Architecture-related factors, moderators, and mediators impacting on delivery capacity, as well as their description and how they are measured. | RQ1        |
| Variables and quality metrics influencing delivery capability | Positive or Negative. Explain                                                 | RQ2-3      |
| Measurement/Metric for delivery capability  | Metrics defining delivery capability                                         | RQ2        |
| Evolution perspective                      | Does the paper discuss variables in the evolution perspective (over time)? | RQ4        |
| Type of study                              | Controlled experiment, case study, action-research, other observational studies. | N/A        |
| Contextual information                     | Characteristics from organizations, products, teams, and projects.          | N/A        |
| Architectural elements                     | Passage detailing the architectural elements or issues                      | RQ1        |
| Concrete architecture                      | Evidence of implementation of the architectural style into a concrete architecture | RQ1        |

Table 3. Quality appraisal criteria

- **Quality Criterion**
- **Category: questions on aims**
  - Are the objectives, research questions, and hypotheses (if applicable) clear and relevant?
  - Is the suitability of the case to address the research questions clearly motivated?
- **Category: questions on design, data collection, and data analysis**
  - Do the authors describe the cases (samples or experimental units)?
  - Do the authors describe the design of the study?
  - Do the authors describe the data collection procedures and define the measures?
  - Do the authors define the (quantitative/qualitative) data analysis procedures?
  - Is a clear chain of evidence established from observations to conclusions?
  - Are threats to validity analyses conducted in a systematic way and are countermeasures taken to reduce threats?
- **Category: questions on study outcome**
  - Do the authors state the findings clearly?
  - Is there evidence that the study can be used by other researchers/practitioners?

4 CONDUCTING THE REVIEW

This section presents general issues with SLR process’ execution, as mentioned, the full protocol is available at [16]. Figure 1 presents the timeline of the research process. As shown, some activities were performed several times on different sets of sources. For illustration purposes, this section gives only representative samples to convey decisions taken during the research process.

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4.1 Automatic Search Process

The automatic search process was carried out between January and February 2019. Tables 4 summarizes the results.

From the 468 papers, we selected 25 for the full reading and extraction. As shown in Table 1, all researchers participated in the voting process. We used JabRef reference manager as a tool to support this activity during the automated search process.

From these 25 sources, we excluded 13 papers after the full reading. Mostly, these exclusions were motivated by (1) the lack of presentation or discussion of architectural elements, for instance, see [3]; and/or (2) the lack of an empirical/experimental study providing evidence, for instance, see [12].

Data extraction was performed verbatim for all twelve papers remaining. We used templates in word processing software to instantiate the data extraction form previously presented (Table 2). To assure consistency, the research team reviewed all extracted data.

The aforementioned process, including quality checks, was followed for both the sources identified through the automatic search and the snowballing search process.

4.2 Snowballing

The 12 sources included in the automated search were used as seeds to the snowballing process. Following the guidelines by [54], we reviewed the suitability of these 12 sources to act as seeds. Out of the 12 seeds, three sets of authors repeat (Bellomo, Chen, and Shahin and Babar). Nonetheless, we decided to keep all papers from the automatic search method to use as seeds because:

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• The two papers by Bellomo look at different aspects.
• Though papers from Chen and Shahin and Babar might describe the same research, the difference in publication year might result in losing forward citations if only the newest ones are selected (y. 2018).

We used both forward and backward snowballing in [54]. For each source, two researchers applied the selection criteria using the paper titles in their references section. Besides, we noted and discussed discrepancies. Likewise, we searched for papers citing each source in the aforementioned search engines (forward snowballing) and applied the inclusion/exclusion criteria.

From these references and citations, we selected 21 candidates from the backward snowballing and 18 from the forward. Finally, we reviewed these 35 candidates in full reading and, based on the selection criteria, and two new references were included in the final set for analysis, resulting in fourteen papers in total (see Table 8).

5 FINDINGS
This section describes the outcomes of the SLR process, conveying factual information about our findings. Synthesis and interpretation is left for later sections.

5.1 Overview
The studies’ publication period ranges from 2012 to 2018. The median for the cumulative publication frequency data is 2016. Figure 2 shows the overall distribution over the years in an ascending trend. Publication venues listed in Table 5 are diverse with almost one paper per venue, except for the Conference on Software Architecture, with three publications, which is the main subject of this paper. It is probably due to the small number of publications, but it calls attention to the variety of topics in which software architecture and delivery capability have been addressed, including the Internet of Things, Dependable Systems, and Software Process.

![Fig. 2. Publication year distribution](image-url)
Table 5. Publications venues and frequency

| Publication Venue                                                                 | Frequency |
|----------------------------------------------------------------------------------|-----------|
| Working Conference on Software Architecture (WICSA) and International Conference on Software Architecture (ICSA) | 3         |
| International Conference on Software Engineering (ICSE)                          | 1         |
| International Conference on Dependable Systems and Networks (DSN)                | 1         |
| Hawaii International Conference on System Sciences (HICSS)                       | 1         |
| International Conference on Product-Focused Software Process Improvement (PROFES) | 1         |
| International Conference on Internet of things, Data and Cloud Computing (ICC)   | 1         |
| International Symposium on Empirical Software Engineering and Measurement (ESEM)  | 1         |
| Colombian Conference on Computing (CCC)                                          | 1         |
| **Total of conference papers**                                                   | **10**    |
| Empirical Software Engineering (EMSE)                                            | 1         |
| Information & Software Technology (IST)                                          | 1         |
| IEEE Software                                                                    | 1         |
| CrossTalk: The Journal of Defense Software Engineering                           | 1         |
| **Total of journal papers**                                                      | **4**     |
| **Total**                                                                        | **14**    |

5.2 Identified Studies

Bachmann et al. [2] discuss lessons learned from software projects concerned with how architectural tactics can sustain rapid and agile software development. The authors point out three distinct tactics that can provide the degree of architectural stability required to support the next iterations of development: (i) align feature-based development and system decomposition, (ii) create an architectural runway, and (iii) use matrix teams. From these tactics, the first two concern software architecture. Feature-based development and system decomposition alignment are essential to “create a platform containing commonly used services and development environments either as frameworks or platform plug-ins” to develop new features upon the common platform. In the architectural runway, the “agile teams build a runway of infrastructure sufficient to support the development of features in the near future.”

Bellomo et al. [6] present a comprehensive investigation regarding the factors that enable or inhibit “rapid fielding.” It seems to be a concept borrowed from the military jargon, which resembles our understanding of (rapid) delivery capability. The authors conducted an observational study based on interviews, focusing on projects adopting an iterative process to investigate the “rapid fielding” influencing factors. Although the research is comprehensive regarding the factors affecting rapid fielding, some aspects are specifically related to software architecture. Interviewees from two organizations said they are starting to keep a list of design decisions along with an incremental architectural change plan that could reduce the likelihood of a big-bang response, which could affect the delivery capability. Also, it is possible to identify a concern with making architectural problems visible to the business area.

Bellomo et al. [5] present a similar research goal and methodology compared to their previous work. However, it focuses on architecture decisions for achieving deployability goals. Interviewees from three software projects with different deployability goals engage the study. Four general deployability goals, also called continuous delivery goals, are identified as enabling: (i) build automation and continuous integration, (ii) test automation, (iii) deployment and robust operations, and (iv) synchronized and flexible environments. From these goals, the authors gathered a set of architectural decisions. Respectively to the four general deployability goals, some examples of deployability tactics

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include (i) maintenance of existing interfaces, (ii) encapsulation, (iii) to increase computational efficiency, and (iv) virtualization.

Chen [12] provides lessons in migrating their custom software applications to CD. Those of most interest are related to what architecture implies to CD. Four requirements affecting the software systems’ architecture are identified and discussed. Deployability is the first mentioned because software applications are “deployed to several testing environments multiple times a day and deployed to the production environment once or twice a week.” Security is mentioned since “the security vulnerabilities of the application during the start-up time become more important, as attackers (hackers) get more opportunities to attack the software during its start-up time.” Another important requirement is loggability given that the architecture must be prepared to log “sufficient information for diagnosis and troubleshooting when issues arise” and, at the same time, make logs “concise enough to not log anything that does not justify its cost.” Lastly, modifiability is mentioned as an essential requirement “to allow constant incremental adding of small new features.”

Villamizar et al. [52] present lessons learned when migrating a monolith application to microservice architecture in a cloud environment. Because of the particular context of cloud computing, more precisely using the Amazon Web Services, the authors focus on more technical aspects of the application on a cloud service such as configuration, performance, and economic aspects. Regarding delivery capability, the authors state that “the use of continuous delivery strategies in microservices can be a time-consuming task, due to repetitive and manual tasks must be executed in each deployment; the use of automation tools are mandatory to save time and gain agility.” These observations should be interpreted taking cloud computing into account. Nevertheless, automation appears as an important factor affecting delivery capability.

Balalaie et al. [3] also investigate the microservice architecture in the context of cloud computing. They report the experiences of PegahTech in migrating BackFactory, a commercial mobile backend as a service, to microservices in the context of DevOps. The paper does not focus on specific delivery capability aspects related to the architecture, even though it is possible to identify several elements in the study. For instance, the migration was driven by the need for decentralized data governance and automated deployment. The former, because shared databases affect deployability. And the latter due to a more significant number of deployable units (i.e., microservices). Furthermore, several architectural patterns are used in the migration because of the microservice architecture. These include bounded context, circuit breaker, load balancing, and service discovery, which also affect deployability.

Chen et al. [13] conduct a participatory case study to understand and adapt agile analytics practices to the context of big data systems. The main goal was to allow data scientists and other stakeholders to increase value discovery amount and frequency. The authors identified software architecture methods as a key enabler for addressing this issue as they can address both business and technical aspects. The method Architecture-centric Agile Big data Analytics (AABA) was developed collaboratively over 10 cases (i.e., big data projects) to provide a basis for value discovery, planning and estimating cost and schedule, supporting experimentation, and enabling continuous delivery of value. The method includes an iterative design method for big data systems based on well-known design primitives (patterns, tactics, references architectures, and technologies).

The study in [48] is one of the closest related to the goal of our synthesis study. They assert that “a critical dimension of CD is to explore and understand the role of software architecture in transition to CD practice, i.e., how software should be (re-)architected to enable and support CD principles (e.g., frequent and reliable deployment).” The study interviewed 16 participants from different organizations. The interviews focused on identifying architectural principles necessary for the CD practice, which are enumerated here: (i) small and independent deployment units (e.g., microservices), (ii)
not too much focus on reusability (to reduce dependencies), (iii) aggregating logs (using external tools to aggregate and abstract the log data over time), (iv) isolating changes (using practices such as bounded context from domain driven design and feature toggles), and (v) testability inside the architecture (to support automation).

Lehmann and Sandnes [33] propose a framework designed to support architects in selecting a strategy and technology stack for implementing continuous delivery. Their framework on microservice-based software systems, and its organization is based on two interviews and existing literature. Based on a set of criteria considered relevant to the development and delivery, they enumerate five criteria: (i) testability, (ii) deployment abstraction (related to the level of automation), (iii) environment parity (development, testing, and production), (iv) time to deploy (in minutes), and (v) availability adequacy (due to deployment or resource scaling). Except for time to deploy, all criteria have a three-level scale to assess the continuous delivery strategy. For instance, environment parity has different levels according to the number of manual steps and configurations necessary to run the system on each environment. The three levels are disparate (in which parity is ensured manually on development, testing, and production machines), distinguishable (where some differences do exist but can be easily mitigated), and equal (in which the same outcomes are expected from the software in any environment).

Martensson et al. [39] investigate impediments for implementing continuous integration. They interviewed 20 experienced software developers asking them to describe the impediments and later showing them a list of impediments found in technical literature. Regarding software architecture, the main factors affecting continuous integration practices are related to “system thinking,” which includes “modular and loosely coupled architecture.” As mentioned in several studies, the respondents commented that a modular architecture avoids problems where many teams want to make changes in the same component, favoring to break down the work into small chunks and working in parallel.

The study in [13] is an extension of [12] discussing challenges that emerged after adopting a microservice architecture. These new challenges are associated with the increased number of services, evolving contracts among services, technology diversity, and testing. Contracts among services, for instance, has a large impact on delivery capability. The robustness principle, related to the contracts among services, defines that services must be conservative in what they send and liberal in what they accept so that they can evolve without breaking compatibility. Also avoiding breaking compatibility, the expand and contract principle adds new interfaces instead of modifying them to allow consumers to migrate the new interfaces gradually. The author concludes with considerations regarding the added costs due to these new complexities and challenges. According to their experience, building the CD platform took a team of eight people four years. And for that reason, “the microservices approach is for handling complex systems that require high speed changes.”

Ivanov and Smolander [28] explore the influence of serverless architectures on DevOps practices, focusing on CI, CD, and monitoring. In this study, a build pipeline was designed and implemented using the Design Science Research methodology in sprints of two weeks. In the sprints, the study participants discussed in a workshop the relevant technical considerations for designing and implementing the pipeline. The findings of the discussions in workshops showed that 18 out of 27 automation practices are affected by the serverless architecture. It includes testing and QA (e.g., mockups and proxies), monitoring (e.g., log aggregation), and build process (e.g., build artifacts managed by purpose-built tools) practices.

Schermann et al. [46] focus on empirically characterizing the state of the practice of continuous experimentation practices. Even though continuous experimentation is not the theme of this synthesis, it has a large intersection with CD. They adopt a research methodology similar to the other studies using interviews and a survey. One of the technical practices identified in the study is the necessity of automation for CI and CD. Regarding software architecture and its
implications for CD (and by extension, continuous experimentation), the findings show the importance of a loosely coupled architecture usually materialized in the form of microservices. Also, the study reveals that feature toggles are important mechanisms to circumvent architectural limitations.

Shahin et al. [49] conduct interviews and a survey to address a similar goal of this research, which is how software systems should be architected for continuous delivery and deployment. One important concern of their research is acknowledging that monolithic architecture is predominant in software industries. By proposing a conceptual framework to support (re-)architecting a system for CD, they indicate architectural attributes that should be augmented/improved if organizations want to achieve CD with, for instance, their monoliths. The main findings of the study are: (i) “small and independent deployment units” is an alternative to monolithic systems and represent a foundation to design CD-driven architectures, (ii) monoliths and CD are not intrinsically oxymoronic, and its challenges can be mitigated (e.g., reducing test run times by improved test quality), (iii) identification of first-class quality attributes in the CD context (i.e., deployability, modifiability, testability, monitorability, loggability, and resilience), and (iv) CD requires operations-friendly architectures.

6 QUALITATIVE ANALYSIS AND SYNTHESIS

As data collection, we performed the SLR process described in Sections 3 and 4. Thus, primary data sources are the fourteen original papers, from which we extracted relevant qualitative information according to the data extraction forms. Even though 14 papers might not seem like a large sample, the amount of qualitative evidence uncovered by the data extraction process needs a systematic method for its synthesis.

Since we target to develop an initial theory on architecting for CD, we considered different perspectives on which type of theory we could achieve. Mainly considering the type of empirical studies obtained from the SLR, we adopted a synthesis and analysis approach based on GT [51]. Grounded Theory has been extensively exploited for data synthesis in software engineering studies [10][15], though its application has some criticism [50]. In this study, we take cue from [50] and provide evidence of our application of GT procedures.

We aim to develop an initial theory on architecting for CD as a result of the synthesis. Since there are several theory traditions, it is convenient to explicitly state which one we are aligned to in order to avoid misinterpretations. Three theory traditions are pervasively discussed in the technical literature, namely [22, 23, 35]: (1) hypothetico-deductive (alternately referred to by theorists as nomothetic, positivism, or empirical-analytical); (2) inductive-synthesis (alternately referred to as idiographic, grounded theory, constructivism, or interpretive theory); and (3) critical theory (alternately referred to as radical, neo-Marxist, or social justice theory). Given the type of data collected in the primary studies and the synthesis strategy used in this research, we are constrained to adopt the inductive-synthesis view. Its primary goal is to depict what is occurring in a particular situation, by clarifying meanings and interpretations. Furthermore, it should be highlighted what we mean by an initial theory. Carroll and Swatman [9] indicate theories have several development levels, from minor working relationships, which are concrete and based directly on observations, to all-embracing theories that seek to explain. Therefore, due to the diverse and relatively small set of 14 primary studies, we understand that the theory developed in this research seeks to describe the entities and working relationships, which are all grounded on the evidence uncovered by the data extraction.

Initially, we familiarized ourselves with the data and performed Open Coding, which is the process of fracturing the data to identify categories, properties, and local dimensions [51]. Then, we assigned each researcher a set of fields in the data extraction form to keep the consistency of interpretation. That researcher would perform the open coding of the 14 data sources considering just the chunks of text in the fields assigned to him. Work progressed in timeboxed
intervals of two weeks, where the research team discussed uncovered codes. This process was supported using QDA Miner Lite\(^2\), and it led us to the identification of four significant phenomena, explained later in the next section.

Based on the major categories, we started the Axial Coding, which is the process of reassembling/regrouping codes by relating categories to subcategories to explain the phenomena of interest [51]. Mainly, axial coding was carried out in plenary meetings by the research team, where the reviewers discussed the axial codes and the pertinence of their associated open codes. The first round of the axial coding resulted in a hierarchy of codes relying heavily on a classification that did not have a good fit in describing and explaining the phenomena. So, we decided to develop a paradigm, similar to the one in [51], to organize subcategories and clarify the explanations. This paradigm provides an abstract theoretical structure that allows to describe the synthesized knowledge. Thus, each identified concept plays the role of a construct in the paradigm, and these concepts are related according to associated propositions. The definition of such a paradigm allows us to systematically explain each phenomenon, as well as to check for consistency and missing constructs in the developed theory. As a tool to document this process, we used Kumu.io. For each category representing a phenomenon, we created memos and updated as it evolved.

Both open and axial codes were discussed and thoroughly reviewed in the plenary meetings. We repeated these activities until the analysis produced no new codes or no re-organization of the axial codes. We do not claim to achieve theoretical saturation as we did not perform additional data collection. However, from the data sources, we could not identify new codes emerging.

Finally, with each phenomenon explained, we searched for the core phenomena (category) and possible relationships among them in the Selective Coding, which is the process of systematically relating the categories and validating their relationships [51]. We identified the core phenomena in the plenary meetings, and then researchers searched for links explaining the overall theory grounded on data. In this step, we adopted both Kumu.io (to analyze categories) and QDA Miner Lite (to search for groundedness).

As an SLR, the research goal is to synthesize evidence. In this sense, the developed theory is limited to the explanation capacity and depth of the identified primary studies. In other words, there is no possibility of emerging a theory contradicting the literature or presenting something completely unprecedented. The theory is solely grounded on the sources of empirical evidence. Once all theoretical structures emerge from the empirical evidence, we understand these elements resonate with the experience of software architects (participants from primary studies), contributing to theoretical validity.

7 A THEORY OF ARCHITECTING FOR CONTINUOUS DELIVERY

This section presents the grounded theory of Architecting for Continuous Delivery. Figure 3 presents the paradigm which evolved through our application of grounded theory.

This paradigm contains the following element types:

- Phenomenon: Represent the central empirical situation that emerged in the analysis. There are only four phenomena identified in our theory, and we will explain them in this section.
- Context: These elements form the setting to give meaning to other elements. For example, “type of system” or “cost overrun”.
- Actions and interactions: These are not present in the instance of the paradigm, but it’s an abstraction that we included to simplify the design of the paradigm. There are four element types in this abstraction.

\(^2\)https://provalisresearch.com/products/qualitative-data-analysis-software/freeware/

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Fig. 3. Paradigm developed for the grounded theory

- Strategy: A high-level action to achieve an effect. For instance, "Applying Design Patterns" is a strategy to enable "Modularization" (one of the five phenomenons in our theory).
- Practice: Represent routine procedures to achieve a Strategy
- Technique: A technique is a determined way of implementing a Practice or Strategy. Examples of identified techniques are Feature Toggle or Container diagrams.
- Design Pattern: Eight design patterns appeared named in our theory; they are all related to Strategy "Applying design pattern" with a “Is A” relationship.

- Quality Attribute: A desirable property of the system 3
- Principle: Represent agreed-upon beliefs for which there is a shared understanding of the sources. Examples include Conway’s Law, the single responsibility principle, and design for testability.
- Effect: These are the observed effects of adopting the Strategies, Principles, Practices and Techniques related to Architecting for CD.

The previous element types are connected through edges that have the following semantic:

- Why: these relationships try to explain reasons or motivations for the phenomenon to happen. For instance, we interpret Modifiability (quality attribute) as a motivation or a target property when performing the Architecting for CD phenomenon, so these elements are connected using a why relationship.

- With what consequence: these relationships represent what are the implications when a phenomenon occurs. For instance, the practice of Creating readable logs achieves improvement on the system Monitorability (effect), when Supporting Operations (phenomenon). This way, the practice is connected to the effect using a with what consequence relationship.

- How: these connections explain how a phenomenon happens through a set of actions/interactions/interventions. For instance, the strategy of applying Deployability Tactics is a way of Improving Deployability (phenomenon). Thus, these elements are connected using a how relationship.

3 We purposely deviate from the ISO/IEC 25010:2011 [27] definition of quality attribute as our understanding of this term in this theory is phenomenological not theoretical.
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• Whom: these relationships refer to contextual elements such as actors who are involved in a phenomenon. For instance, in the Continuous Evolution (phenomenon) of software systems, Experienced software developers are key. Therefore, these elements are connected using a whom relationship.

• Where: these relationships refer to contextual factors such as locations, situations, or conditions describing the phenomenon. For instance, the different Types of Systems (context) in which evidence on the Architecting for CD phenomenon are found. This way, these elements are connected using a where relationship.

• Is A: these relationships describe forms of specializations among elements. For instance, the Serverless Architecture (strategy) is a specialization for Adopting Architectural Styles (strategy). So, these elements are connected through an is a relationship.

In addition to the semantic in theory, a connection can be reinforcing (positive), undermining (negative) or neutral, when we found no evidence to suggest either of the previous classifications.

7.1 The theory in a big picture

Figure 4 shows the grounded theory in an overview. Mainly, it involves four phenomena (larger circles) providing the following explanation: “Architecting for Continuous Deployment (core phenomenon) involves software design concerns primarily, but it should also target Improving Deployability (support phenomenon) to ensure the continuous delivery of valuable software. In this sense, Supporting Operations (support phenomenon) is key to reach downstream activities frequently successfully. Also, decisions made for the system architecture impacts its Continuous Evolution (support phenomenon) in the long-term perspective.” The following sections describe each phenomenon in detail.

7.2 Architecting for Continuous Deployment

This is the core phenomenon of the developed theory, and the following memo (in the textbox) describes it textually in an overview, emphasizing (in bold) the main involved concepts (open codes).

In the face of symptoms like integration issues and refactoring not being enough to handle the amount of technical debt, leading to major maintenance cycles, long software releases, and schedule delays, which are probably caused by the adoption of a tightly coupled architecture, Architecting for Continuous Delivery is a phenomenon occurring in different types of systems. In this context, experienced software developers adopt different strategies to ensure modifiability, which is a factor for delivery capability by implementing design principles. For that, important strategies take place like adopting architectural styles, such as Microservices and Serverless architectures, applying design patterns on the implementation of these styles, and using supporting practices and techniques, such as Domain-Driven Design and Consumer-Driven Contracts.

From the collected sources, the experiences on architecting for CD are mainly motivated by poor modularization symptoms [12] [6]. Bellomo et al. [6] mention major maintenance cycles and refactoring not enough to handle the amount of technical debt as examples of such symptoms. Additionally, poor modularization symptoms also regard tightly coupled architectures, like shared databases and monolithic architectures [48]. Other symptoms include schedule delays and integration issues [2].

The memo presents modifiability as a factor for delivery capability [12]. Furthermore, the modifiability quality attribute motivates architecting for CD, which explains why several deployability tactics in [5] are, actually, new.

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*The diagram is available at: https://kumu.io/brenofranca/architecting-for-cd-selective-coding*

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Fig. 4. Paradigm developed for the grounded theory interpretations of modifiability tactics. Furthermore, design principles drive the achievement of modifiability through design patterns, architectural styles, and practices.

CD is a practice targeting the delivery of valuable software in frequent and constant pacing. As the product team deploys software releases into production regularly, it is not feasible to make it with larger software modules. This way, an important principle guiding CD is to work with small and deployable units [49]. This principle is a step further in the balance of other known principles like the single responsibility principle (SRP) and loose coupling towards a deployment mindset.

As a consequence of the small and deployable units principle, we found suggestions of having smaller databases [48]. Also, in this same source, we found that databases should be treated as deployment units [48]. Another consequence regards the over reuse of components, which can lead to (1) increased inter-team dependency and (2) losing testability [49].

In addition, Bellomo et al. [5] shows how these principles work together describing that SRP improves testability and deployability. The authors express that when teams achive the modularization of features, "then lower coupling, and increased cohesion enable deployment and continuous delivery..." [5].

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Furthermore, we identified a few occurrences of the robustness principle and system thinking as relevant when architecting for CD [13]. Martensson et al. mention System thinking as a surprise, since it leads to designing the entire system rather than using a simple design and evolving it by integrating small increments [39].

As mentioned in the memo, this phenomenon has three types of actions/interactions when architecting for CD: adopting architectural styles, applying design patterns, as well as supporting practices and techniques. These actions and interactions are somewhat general for software architecting. However, the specific styles, patterns, practices, and techniques make the difference in the CD context. Architectural styles in the context of CD mainly include Microservices (with REST) [48] and Serverless [28].

Chen [13] reports an increased operational complexity when adopting the microservices architecture. This consequence is also reported in [48] when discussing architectures for CD, explicitly mentioning operations overhead as an example of cause for negative results, culminating in the failure to achieve the potential benefits. On the other side, Chen [13] also reports that microservice facilitates incremental changes. Another benefit of adopting microservices is also reported by [46] regarding that it facilitates technology adoption. As a consequence of the former benefit, microservices also reduces database constraints [13]. Besides microservices, Shahin et al. [49] identifies the use of the vertical layers style as a means to achieve the principle of small and independent deployment units.

Some design patterns appear as building blocks for architecting microservices but they are also used to design with other styles like serverless. This is the case of the structural API Gateway (a variation of the Facade pattern), which is usually implemented along with the Authorization pattern. Service Discovery is important considering microservices are organized in the choreography way, rather than orchestration. The Circuit Breaker for fault-tolerance, and others like Tolerant Reader, Broker, and Event-sourcing. Balalaie et al. [3] exemplify the use of several of these patterns when describing concrete architectures in the context of Spring Cloud Netflix, which integrates the Spring framework with the Netflix OSS project.

Regarding practices and techniques supporting the act of architecting for CD, we identified more general ones like container diagrams and the agile practice of simple design [13]. Additionally, several techniques like Branch by Abstraction, Dependency Injection, and Deployment Configurations appear to discuss solutions for migration from monolithic to microservices, general service injection and decoupling service logic from its configurations, respectively. Lehmann and Sandnes define three levels of expressiveness for deployment configurations: “(1) Highly expressive: no highly error-prone manual steps, little learning required; (2) Somewhat expressive: some manual steps; (3) Manual: largely manual deployment, error-prone” [33].

Consumer-Driven Contracts and Domain-Driven Design (DDD), including the Bounded Context strategy, are two other practices supporting the goals of architecting for CD. Balalaie et al. mention the benefit of maintaining contracts when handling changes in [3] and Domain-Driven Design is mentioned in [48] to “identify autonomous business capabilities of software architecture”, reducing coupling.

This core phenomenon is contextualized into information systems [6], [49], [12], [13], large-scale systems [6], [39], and big data projects [11]. Such context also involves the presence of experienced software developers, as in all the other three supporting phenomena.

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7.3 Supporting Operations

Supporting operations becomes a critical success factor for enabling Continuous Delivery. Experienced software developers need a holistic view of the development process. Increased deployability and monitorability are the main desired effects. To increase deployability, the main strategies are to design environments that maintain parity and reduce set up times. Experienced software developers must design their environments, so that setup (and tear down) times are reduced. Environment parity includes "architecture infrastructure, test architecture, and automation". Maintaining environmental parity leads to increased deployability. Finally, maintaining the environmental parity strategy requires close collaboration between development and operations to assure that needs and operational requirements are considered and incorporated into the architecture. Close collaboration can be achieved by giving developers more responsibilities at operations. Logs are a key interface for both sides, and the collaboration between development and operation should ensure that readable logs are designed and maintained for improved monitorability, with the consequence of improved issue detection.

Supporting operations represent the phenomenon that leads organizations to deliver sustainable continuous deployment processes. By applying the strategies associated with this phenomenon, organizations are able to sustain their investments in continuous deployment. As presented in the memo, two main strategies emerged within this phenomenon: designing environments and maintaining environmental parity.

Environments should be designed to reduce setup times. These reduced setup and teardown times lead directly to increased deployability [12]. Furthermore, maintaining environmental parity is a strategy which aims at maintaining a reasonable equivalence between the different environments involved in the deployment. We have found evidence that Maintaining environmental parity has the effect of increased deployability [49].

Maintaining environmental parity can be achieved with close collaboration between developers and operations. These collaborations should enable operational requirements to be incorporated into the architecture, and by giving developers more responsibility into operations [48].

Finally, system logs are the key interface to achieve the previous strategy. Teams should design logs so that they are readable by all stakeholders. Creating readable logs has the consequence of improving monitorability, which has the immediate positive effect of improving issue detection [48].

7.4 Continuous Evolution

As organizations seek to increase fast delivery capability and decrease cost overrun, continuous evolution should be a fundamental concern to meet these goals. When implementing continuous evolution, several practices support it, such as technical debt management, design memos, and architectural change plan. Otherwise, the continuous evolution might lead to an excessive focus on speed (ignoring quality attributes), which in turn leads to rapid architectural decay (i.e., architectural debt invisible to business). Another common technique used in this context is feature toggle, even though its usage should be carefully planned since it may increase structural complexity. The formation of the teams is also an important concern for continuous evolution as it requires experienced software developers, which should ideally work in an independent way that, in terms of the Conways’ Law. The software architecture can support the teams’ autonomy with increased instead of decreased deployability.

Continuous evolution represents the phenomenon that depicts how organizations work with their software systems when adopting CD. We found that in some organizations where the studies were conducted, the CD adoption was motivated by the possibility of reducing cost overrun [2] and improving delivery capability [6].
However, these two aspects can translate into an excessive focus on speed, which can bring undesirable consequences, mainly concerned with architectural debt [6]. Still, regarding the studies’ context, experienced software developers are important for implementing continuous evolution as they represented the majority of the participants in some studies [49][39].

The primary studies report several practices to support the continuous evolution seeking to improve delivery capability. These practices are primarily concerned with internal quality aspects of the system under development. In [6], the authors found that organizations are adopting technical debt management practices, like keeping record of design decisions leading to architectural debt. These measures are important to keep the system in a maintainable state and support the developers in assessing the impact of system changes over time. Also, the authors mention the Design Memos, which represents “a minimal design document containing architectural design information”.

Regarding the functional aspects of the system, some practices can be applied as well. In [48], interviewees mentioned and described the use of feature toggles and the branch by abstraction pattern to support incremental changes. Another interesting report related to this issue can be found in [46], in which an investigated organization appreciates “that properly managed and synchronized (e.g., using tools such as ZooKeeper) feature toggles give them more control over their application ecosystem”. However, as alerted in the previous excerpt, when Feature Toggles are not properly managed and synchronized, technical debt and the additional level of structural complexity emerge [46].

Apart from being affected by technical aspects, continuous evolution is also influenced by the team organization. It is noticed in [49] that the Conway’s law influenced cross-team dependencies, causing frictions in the CD pipeline. It shows how important the teams’ responsibilities are and how they should be distributed appropriately among the modules of the system under development since. Hence, the team organization and the software architecture match or mismatch can lead to increased or decreased deployability, respectively.

### 7.5 Improving Deployability

Experienced software developers looking at improving deployability should observe how their decisions affect availability, deployability, and testability. To do so, experienced software developers must follow the principles of deployability architectural concerns, design for testability and minimizing system deployment downtimes. Design for testability has a direct effect on testability. Likewise, minimizing system deployment downtimes has a direct effect on the availability of the software system. At their disposal lies a toolset of actions that can assist them in improving deployability — a smart and efficient test strategy, as a direct influence on the capacity to maintain efficient deployment pipelines. Furthermore, experienced software developers can implement several Deployability Tactics, including automated deployment, use of cloud resources, gradual deployment strategies, and common platforms.

Improving deployability represents the phenomenon that is observable when teams of experienced software developers that are architecting for CD start to look at improving the capacity to deploy software. When doing so, they should take into consideration three main quality attributes: availability, deployability and testability.

There are three principles driving to improve deployability. First, the principle of deployability architectural concerns conveys the idea that experienced software developers must take the deployability quality attribute into account when designing their arquitectures [49]. The second principle of concern is designing for testability. Improving the capacity to deploy a software system imposes challenges to the capacity of the test suite to identify defects. Therefore, the software system must be architected to enable a Test Suite that leverages the tradeoff between thoroughness and performance [33]. Finally, the minimize deployment downtime principle encompasses the drive towards the ideal
situation where new deployment should be accomplished with zero downtime. For instance, when mentioning this principle, Chen [13] goes to the length as affirming that zero downtime is a requirement for Continuous Delivery. This principle has a direct positive effect in Availability.

As a result of these principles, a coherent test strategy is key to improve deployability. It means realising the test strategy is a key factor in the capacity to deploy frequently and continuously. As mentioned, the test strategy must leverage its execution time with its coverages [48]. Also, there is a positive relationship that a coherent test strategy has on obtaining efficient deployment pipelines [13].

Finally, a set of deployability tactics are at the disposal of experienced software developers looking to improve deployability. Automated deployments are a requirement for a sound and consistent capacity to continuously deploy software [13]. Use of cloud resources is another strategy involving the use of cloud computing infrastructure as the deployment platform [52]. Gradual deployment strategy encompasses the practices that enable experienced software developers to select the components and functionalities to deploy, for instance, the use blue/green deployments, canary release, and gradual rollouts [46]. Finally, the common platform is the last named strategy in our theory concerning improving deployability. It refers to potential benefits of introducing a common technology stack to benefit from the knowledge of the experienced developers of the software system [2].

8 DISCUSSION

In this section we discuss the results by answering the research questions using the proposed theoretical structure.

Which architectural characteristics contribute to the delivery capability?

RQ1: What are the variables concerning the concrete architecture (factors, mediators, and moderators) influencing the delivery capability?

The notion of delivery capability can be generally understood as the readiness and competence that teams or organizations have to deliver software, which is usually associated with the desire of delivery frequently. Most of the codes defined as effects in the paradigm described in the analysis are related to delivery capability. Nevertheless, among these codes, deployability is a prominent aspect of the study. Two out of four phenomena in our analysis have deployability as part of their name (architecting for continuous deployment and improving deployability), including the core phenomenon, which indicates the relevance of deployability as an aspect associated with delivery capability.

In short, when looking at the grounded theory (Figure 4), the variables influencing aspects related to delivery capability are represented in the theory. Even though we can not claim that our theory is complete, it does convey the diversity of elements concerning the concrete architecture of a system that supports continuous delivery. Based on the developed paradigm, the factors influencing effects (interpreting delivery capability as an effect in the theory) can be either context or strategies. For instance, the identified design patterns, architectural styles, deployability tactics, as well as the supporting practices and techniques contribute positively for a concrete architecture with improved deployability and, consequently, an increased delivery capability.

RQ2 How does the quality of the concrete architecture impact the delivery capability?

We answer this question focusing on deployability since, as stated in the previous question, it is the most relevant aspect of delivery capability. To answer this question, we interpret the term quality as related to the Principles and Quality Attributes in the paradigm. In the paradigm (Figure 3), both constructs provide the motivation (why) for attaining the Effects. But these Effects can only be attained through the implementation of the Actions and Interactions.
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We, therefore, interpret that a concrete architecture of good quality must abide by the principles and conform to the quality attributes. In the grounded theory (Figure 4), this question can be answered by navigating the positive (green connectors) and negative effects (red connectors). Thus, the phenomena that most contribute to this question are Architecting for Continuous Deployment and Continuous Evolution. Increased deployability is directly related to the Principles: single responsibility principle and Conway's law. Single responsibility principle is crucial for testability, which enables unit testing and other kinds of automated tests that become a requirement when the goal is to deliver continually. Apart from these product concerns, human aspects also impact delivery capability. This is related to Conway's law, which states that the team’s communication structure should mirror the system’s architecture.

Regarding the factors associated with the decreased deployability, one is precisely the result of Conway's law potentially negative side. It occurs when the team’s communication structure is incompatible with the system’s architecture, creating obstacles to effectively accomplishing the activities planned in the process. Another direct negative influence on deployability is the presence of shared databases. This design is a type of tightly coupled architecture that can impact, for instance, independent deployment of software modules or testing them separately.

RQ3: How do these variables relate to each other to contribute to the delivery capability?

We separate the answer to this question in two levels of abstraction related to the paradigm and the grounded theory that resulted from our analysis. The paradigm described in Figure 3 represents a “high-level” answer to this question. It shows a schema describing the possible ways the codes extracted from the primary studies can relate depending on their types. Although it is not a causal model, it essentially depicts how context and quality attributes represent motivators or obstacles to achieve the desired effects through strategies (e.g., techniques, practices, and design patterns) guided by principles. Thus, this high-level structure of the paradigm captures the essential elements involved in the connections among the variables and their contribution to the delivery capability.

Furthermore, the grounded theory in Figure 4 represents the “low-level” answer as it contains all codes defined during the analysis and their relations following the paradigm. Also, it contains the core phenomenon, which describes how software systems must be architected for CD. As an example, we can identify the mechanism (path from context, quality attributes and principles to effects) in the Architecting for Continuous Deployment phenomenon that can be read as “driven by modifiability goals, explicitly described in design principles such as the single responsibility as well as the small and deployable units, experienced software developers adopt the Microservices architectural style to facilitate incremental changes.”

RQ4: How does the effect of the identified variables evolve over time?

The primary studies included in this investigation do not contain enough elements to provide an answer to this question. However, we described the Continuous Evolution phenomenon. Mostly, it explains the continuous evolution of monolithic architectures in a transition stage to a more flexible approach, so we understand the identified strategies in this phenomenon can support the long-term evolution. Furthermore, we understand this question as a relevant topic to be investigated in future works.

9 THREATS TO VALIDITY

We analyzed the threats to validity according to guidelines in [42], [29], but considering the aspects using Maxwell’s categorization as in [41].

We handled theoretical validity concerned with searching and selection bias by possibly capturing multiple sources from three search engines and establishing the entire protocol, particularly the inclusion/exclusion criteria, a priori.

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All the previously known material could be included in the search process (100% coverage). Additionally, we adopted two search methods to reach relevant data sources: search strings and snowballing. All the concepts achieved in the generated theory are grounded on data from empirical studies and rigorously defined using coding procedures and frequent review of the entire research team.

Publication bias is also a concern. We mitigated it by critically analyzing each term from the referred segments and concepts, comparing against all collected information through the constant comparison method and recurring to dictionaries when no conceptual reference could be obtained. Regarding descriptive validity, we unbiasedly defined the extraction form and process before the execution to answer the RQs strictly. Apart from the coding procedures, at least one researcher reviewed all information. Also, the definition of a paradigm explaining the phenomena in a metalevel supports the consistent description of each phenomenon. Although we identified contextual elements in the theory, it is not possible to claim generalizability as the results miss evidence on several other contexts for software development, which could allow the identification or appearance of new codes and categories. Besides, we achieve no saturation for the developed theory, even using a wide search strategy. Likewise, the limits of explanation of the theory are bounded by the limits of the evidence included in the primary sources. Concepts identified and described in the developed theory remain at the level of abstraction provided by the primary studies. For instance, codes like “coherent test strategy”, “experienced software developers”, and “readable logs” may provide no significant addition to the capacity of explanation, but this is the abstraction level presented in the primary studies. Also, this explains the high number of quotations from [49], as it is the one with more depth in details. This way, we understand additional empirical data should be collected regarding software architecture and continuous deployment for the more abstract parts of the synthesis.

Finally, interpretive validity is achieved when the researchers draw conclusions reasonably given the data. A threat in interpreting the data is researcher bias. For the analysis, we adopted rigorous GT procedures executed in parallel by three researchers to avoid bias and solve inconsistencies. Then, the collective codebook evolved iteratively, remaining only consensual information. In addition, we provide complete traceability from the major categories (phenomena) to the raw data segments and the other way round.

10 CONCLUSION

As businesses change and transform their offerings, software organizations seek to adapt to meet user and client expectations. Continuous Software Engineering methods, techniques, and practices are increasingly being employed in this scenario in which technological innovation and contextual uncertainty are relatively common. While CSE represents a vital tool to deal with this scenario, in this paper, we discussed how the inappropriate focus on architectural concerns could affect delivery capability during the software development process. We found 14 primary studies regarding this matter. Considering it is a specific aspect of a modern software development context, it is possible to say the research community is at least aware of its importance. On the other hand, it is notably the absence of more robust studies in the set of investigations found in this systematic review. Despite this limitation, this investigation shed light on the mechanisms behind software organizations’ delivery capability from the architectural perspective. The following points were salient in our analysis:

- Software Architecture plays a crucial role in the capacity to deliver software frequently, especially in the CD context;
  - The technical literature is abundant in examples of design patterns and principles related to this subject;

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Modularization is an essential aspect of software architecture in CD; Supporting operations should be considered from the beginning, since the software architecture definition, to improve the systems’ monitorability and increase deployability. Moreover, organizations should enable developers to accept more responsibilities at operations; The continuous evolution of software systems is an important aspect when organizations are concerned with increasing delivery capability and avoiding cost overrun. However, it requires particular attention to managing technical debt; Improving deployability is, as might be expected, a major concern for CD. It includes strategies related to deployability such as automation and the use of cloud resources. Also, defining test strategies and minimizing deployments downtime support efficient deployment pipelines and systems’ availability, respectively.

We propose the grounded theory as an instrument for researchers and practitioners diagnosing problems and identifying improvement opportunities in controlled studies or real-world scenarios. The theory can be used to identify similar contextual factors, quality attributes, strategies, and effects as described in this paper that support decision-making in other situations or, at least, help explain them. Also, the four phenomena (axial coding categories) described in terms of the open codes offer different perspectives to understand these scenarios and act upon them. For instance, the phenomenon **supporting operations** can support checking whether the operations are promoting the appropriate strategies (e.g., **designing logs**) to achieve the desired effects (e.g., **improved monitorability**).

Still, the theory is far from complete, and further developments are expected and welcome. Some of the hypotheses for further research were enumerated in this work. Others are yet to come based on new studies or expanded understanding of the CD practice and how to architect for it.

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