Cloud Service Brokerage: A systematic literature review using a software development lifecycle

Full Papers

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Abstract

Cloud Service Brokerage (CSB) is an emerging technology that has become popular with cloud computing. CSB is a middleman providing value added services, developed using standard software development lifecycle, from cloud providers to consumers. This paper provides a systematic literature review on this topic, covering 41 publications from 2009 to 2015. The paper aims to provide an overview of CSB research status, and give suggestions on how CSB research should proceed. A descriptive analysis reveals a lack of contributions from the Information Systems discipline. A software development lifecycle analysis uncovers a severe imbalance of research contributions across the four stages of software development: design, develop, deploy, and manage. The majority of research contributions are geared toward the design stage with a minimal contribution in the remaining stages. As such, we call for a balanced research endeavor across the cycle given the equal importance of each stage within the CSB paradigm.

Key words:

Cloud service brokerage, Cloud computing, Literature review, Software development lifecycle

Introduction

Cloud computing is undeniably one of the biggest trends in the IT industry today. A recent survey from Eurostat (Giannakouris and Smihly 2015) indicates that 46 per cent of European enterprises are *highly dependent* on cloud computing. This number is consistent with the expanding global Software-as-a-Service (SaaS) market, which is expected to grow at a Compound Annual Growth Rate (CAGR) of 8.14 per cent by 2018, the growing Infrastructure-as-a-Service (IaaS) at USD 16.5 billions in 2015, a 32.8 per cent increase from prior year, and the escalating Platform-as-a-Service (PaaS) market at CAGR 36 per cent by 2026 (Columbus 2015). Markets and Markets (2015), an industrial research company, estimates that the global cloud service brokerage market is expected to grow from USD 5.24 billion in 2015 to USD 19.16 billion by 2020, or a CAGR of 29.6 per cent during the five-year period. Such rapid increase in cloud computing adoption has led to a proliferation of *Cloud Service Brokerage* services (CSB) in recent years.

The US National Institute of Standards and Technology (NIST) defines a CSB as "*an entity that manages the use, performance, and delivery of cloud services, and negotiates relationships between Cloud Providers and Cloud Consumers*" (Sill et al. 2013). The NIST suggests that there are five actors in the cloud service environment: cloud consumer, cloud provider, cloud broker, cloud auditor, and cloud carrier. From the NIST viewpoint, a CSB's core competency, which differentiates CSB from cloud provider, is an ability to provide *a single consistent interface* to multiple cloud services from different cloud providers. The NIST definition is preferred over other available definitions from Gartner (Plummer et al. 2011) and Forrester (2012), because it incorporates a supply-chain perspective into the definition, i.e., each actor creates some values to the entire CSB business model. In other words, it integrates both the technology and business perspectives into CSB, while the other definitions are technology-driven.

In layman's terms, a CSB is a middleman or intermediary between cloud providers and groups of cloud users, be it individuals or business organisations, and companies that are developing cloud applications. The basic business model of a CSB is to earn commissions from services brokered, just like in a traditional brokerage business model, e.g., an insurance broker. Nevertheless, a CSB provides added value to the services rendered to their business partners than simply acting as a middleman. CSB services should follow standard software development lifecycle to ensure their quality. There are many complementary value added services for CSBs to offer such as advisory service for cloud selection, compliance management, quality assurance, and security management (Casalicchio and Palmirani 2015; Nair et al. 2010). Given these value added services, CSBs are believed to play a critical role in assisting further cloud adoption (Bellamy 2013). In short, CSBs make it easier for sellers and buyers to meet and negotiate a value exchange.

There are many entities offering CSB services. These can be categorised by sector (public vs private), by brokerage or marketplace type (proprietary, platforms, OEMs, white labels etc.), target audience (Business-to-Business or Business-to-Consumer) and so on. Some of the well-known examples from the private sector are Microsoft Azure Marketplace, AppExchange, and Google Apps Marketplace. In the public sector, the UK's Digital Market place through the G-Cloud framework is an attempt from the UK government to catalogue cloud computing services to ease a cloud service procurement process among its public bodies (Bellamy 2013). This project has been exceptionally successful. To date, the project has generated more than USD 675 million (GBP 467 million) in revenues, 85 per cent SME participation, and has resulted in a simpler, clearer and faster procedure for cloud procurement (GovermentDigitalService 2015).

Given the emergence and usage of CSBs, the realisation of such brokering services from a software development perspective should be reviewed to understand their quality. Previous research efforts in this area have been focused on the role and services of a CSB (Wadhwa 2013) or on Service Level Agreement (SLA) based brokering (Mostajeran 2015). Little or no effort has been made to evaluate the existing CSB services from a software development point of view. This paper provides an academic literature review on the CSB topic in order to (1) provide an overview of the CSB research status, and (2) give suggestions on how CSB research should proceed. To achieve the aims, a descriptive analysis and a review based on software development lifecycle are conducted. The software development lifecycle is a fundamental mechanism to system development. It ensures that a software system, like the CSB, meets its intended objectives; performance-wise and budget-wise (Kan 2002). Every step in the lifecycle is equally important to ensure a software quality. We believe that all stages are significant for a long-term success of the CSB services and research.

This paper proceeds as follow. After the introduction to the topic set out in this section, section II describes method and framework adopted to guide this literature review. Section III provides a descriptive analysis of CSB literature from 2009-2015. Section IV presents the literature reviews following four software development stages –design, develop, deploy and manage – along with suggestions for future CSB research. Section V summarises key ideas presented in this paper.

Method and framework

This literature review adopts guidelines suggested in Webster and Watson (2002). We aim at a complete coverage on the CSB topic without any restriction to method, discipline, journal, and region (Webster and Watson 2002). To achieve this aim, we opt for a systematic review of the existing literatures on this topic that are available on the digital libraries such as IEEE Xplore, ACM, ScienceDirect, Scopus and Google Scholar. We apply a descriptive analysis and a software development lifecycle approach for this purpose. The descriptive analysis provides insight into CSB research directions and highlights the open challenges including future research areas. We used the term "cloud service brokerage" and "CSB" to search, for example, for articles on Google Scholar. Our searches using other terms, e.g., application market place, Azure, or AppExchange, did not produce satisfactory results. Our search yielded 25 key publications on the topic from 2009-2015. We then performed a *go backward* and *go forward* review of these key articles to identify additional articles (Webster and Watson 2002). During this process, we identified 20 more publications in relation to the topic. After further scrutiny, the final list was reduced to 41 relevant articles from the original 45 articles identified. Papers were omitted on the grounds that their main focus was cloud computing and not CSB per se.

Usually, CSB functions by aggregating heterogeneous cloud services from diverse providers into a single interface to make them easy for users to consume. This process involves software development activities since CSBs, in some cases, have to re-engineer cloud services to add values or make them compatible to the user requirements. This shows the importance of software development for the success of cloud brokerage services. Therefore, to review the quality and status of the existing CSB literature, we employ a software development lifecycle lens to help us group literatures with similar ideas. The software development lifecycle adopted in this review comprises four critical stages: Design, Develop, Deploy and Manage (Murthy and Marjanovic 2014):

- Design – covers activities such as identification of business and functional requirements, which lead to a preliminary software concept design and ultimately a coding standard.

- Develop – includes software development activities such as coding, static analysis, and software integration.

- Deploy – spans over key software deployment activities like functional testing, load & stress testing, integration testing and application testing.

- Manage – contains business-oriented activities in software development such as software functionality and performance analysis, and business need analysis.

Two researchers, one from Computer Science and one from Information Systems, independently of each other review each paper to assign them into one of the four stages in the software development lifecycle. Discrepancies between researchers were discussed and reconciled to reach a mutual agreement. A key benefit from adopting this approach is to enable the observation of a holistic trend in the academic CSB research. Therefore, we are in a position to identify areas that are over/under researched and give recommendations on how future research initiatives should proceed.

A descriptive analysis of CSB literature

In this section, we offer a descriptive analysis of CSB literature between 2009 and 2015 from two key filters: year of publication, and academic disciplines. We believe that these filters provide an insight in to the trajectory of the CSB research field along with potential areas requiring further exploration.

Available publications on CSBs first appeared in 2009 in the seminal article from Buyya et al. (2009). However, it is not until 2012 that the topic appears regularly in academic publication sources. The number of publication count for 2012 is eight articles. The level of CSB topic appearance seems steady throughout 2012-2014 with a slight decline in 2015. Figure 1 portrays the overall CSB publication counts throughout the last seven years (2009-2015). The decline in 2015 may not signal a decline interest in the CSB topic. The exponentially growing interest in the cloud computing topic from 2009 onwards (GoogleTrend 2016), and the staggering expected growth rate in the CSB market value at CAGR 29.6 per cent from 2015 – 2020 (MarketsandMarkets 2015) suggest otherwise. We believe that the decline can be explained through lack of knowledge of the area and the natural publication cycle.
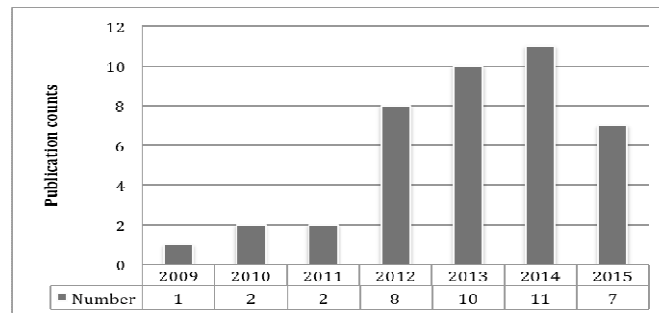

Figure 1 Cloud service brokerage publication counts by year

We next consider CSB articles from a scientific disciplinary filter. We adopt a traditional discipline boundary between Computer Science and Information Systems (Baskerville and Myers 2002). We refer to Computer Science as a discipline "*that is concerned with theoretical and applied disciplines in the*

development and use of computers for information storage and processing, Mathematics, Logic, science, and many other areas" (Dodig-Crnkovic 2002). In this way, Computer Science differs from Information Systems which investigates any interacting phenomena between technological system and social system (Baskerville and Myers 2002).
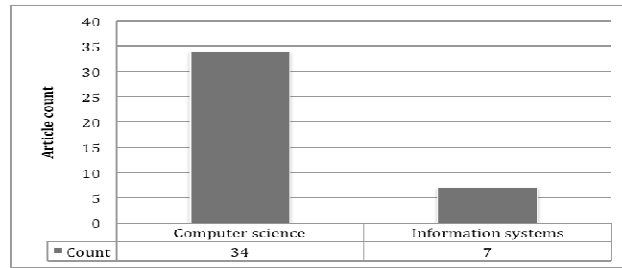

Figure 2 Cloud service brokerage publication count in CS and IS disciplines

Our analysis of CSB publications reveals that most publications (34 papers or 83 per cent) on the CSB topic come from the Computer Science discipline (Figure 2). Only seven papers (17 per cent) are from the Information Systems discipline. These papers are Bellamy (2013; Bratanis et al. (2013; Grivas et al. (2010; Kuada and Olesen (2011; Rogers and Cliff (2012; Stamas et al. (2014; Sundareswaran (2014). Some papers might fall into the borderline between Computer Science and Information Systems disciplines. When this dilemma presents itself, we draw a final conclusion on the discipline definitions from Baskerville and Myers (2002) and Dodig-Crnkovic (2002). Based on this analysis, there is a poor contribution to the CSB topic from the Information Systems community. This could be problematic in the long run, if the trend continues since a successful CSB paradigm requires insights from the Information Systems discipline, especially on the social system part, i.e., How could we understand and identify CSB user requirements? (Barker et al. 2014). Without insights from Information Systems feeding back into the Computer Science discipline, we will not be able to build a CSB with a lasting impact for the users.

CSB literature review by software development lifecycle

This section presents our analysis of CSB literature according to the software lifecycle discussed in the method and framework section. Our classification based on the lifecycle model shows the following results: Design (21 papers or 51 per cent); Develop (7 papers or 17 per cent); Deploy (5 paper or 12 per cent); and Manage (8 papers or per cent).

It can be observed that papers in the design stage dominate the others. The result clearly indicates an unbalanced research endeavour on the CSB topic. Thus, we call for a greater research contribution on the other stages since we believe that all stages are significant for a long-term success of the CSB research. In the following paragraphs, we present the literature review following each stage in the lifecycle.

Design stage

Papers in the design stage appear most frequently in this review. This makes sense given the nascent stage of CSB research. We observe that there are two key streams of papers in the design stage: operational and strategic.

At the operational level on CSB design, we observe researchers incorporating numerous operational requirements, especially those on the technology side, into their CSB designs. The two most common operational requirements observed in this stream of literature are: user requirements (Kang et al. 2014; Sundareswaran et al. 2012), and SLA (Badidi 2013; Jrad et al. 2012; Kang et al. 2014; Mostajeran et al. 2015; Sundareswaran 2014). SLA research is particularly common in cloud computing. Other popular requirements include: interoperability (Fowley et al. 2014; Jrad et al. 2012; Kang et al. 2014) and quality of service (Badidi 2013; Kourtesis et al. 2014a; Kourtesis et al. 2014b; Veloudis et al. 2015), again reflecting cloud computing research in general. The remaining papers relate to other common cloud computing themes: cloud vendor resources (Amato et al. 2013); security (Monteiro and Vasconcelos 2013; Nair et al. 2010); privacy (Monteiro and Vasconcelos 2013); service governance; quality assurance; optimisation (Simons et al. 2014); and legislative compliance (Casalicchio and Palmirani 2015). Two

papers offer schemes to classify existing CSB technologies. Wadhwa et al. (2013) present a utility matrix that could help businesses classify and select a CSB based on their preferred requirements. Fowley et al. (2013) present advanced and descriptive schemes for CSB classification. These consolidation views on CSB serve as a basis for future CSB designs.

The strategic streams of literature on CSB design emphasise new directions for CSB design approaches. It has less to do with the technology and more on adding a business perspective into the design. Buyya et al. (2009) deliver a futuristic CSB architecture through a utilisation of virtual machines. Duan et al. (2014) incorporate business and economical requirements into the CSB design. Research gaps between practitioners and academia are identified in Wadhwa et al. (2014) and Grozev and Buyya (2014) along with roadmaps to tighten them. Some of the interesting research gaps identified are alienation of industrial research from academic rigor, difficulty on the academia to translate research outputs into commercial products (Wadhwa et al. 2014), difference in research focus between academic and industrial research, e.g., academic is interested in SLA-based brokering, but industrial research is interested in trigger-action brokering (Grozev and Buyya 2014). Suggested longer-term roadmaps to tighten the gaps are: improvement in security and service models, additions to CSB service sets, industry implementable revenue models and CSB registry (Wadhwa et al. 2014).

Research outputs for the vast majority of papers, either in the operational or the strategic categories, are models, ontologies, architectures, and frameworks for CSB based on concepts that the authors are interested in incorporating into CSB. The most common research method employed is modelling, which is reflective of Computer Science discipline.

While more papers are oriented toward the operational stream than the strategic stream, there would seem to be an opportunity for design papers that focus on (1) adopting more strategic issues into the CSB design, and (2) combining operational with strategic issues in the CSB design. Research outputs from the management stage (which will be discussed separately below) should drive research in the design stages, especially for those concerning strategic issues in design. Giving insights from a leading Information Systems theory, like task-technology fit (Goodhue and Thompson 1995), which posits that a system is more likely to be successful if the system capabilities (i.e., operational requirements) match the task (i.e., strategic directions), we are confident that a more holistic approach to CSB research, i.e., combining strategic and operational issues into CSB design, will promote CSB success.

Development stage

Seven research papers were categorised as "Development". They tackle key issues in CSB business models namely, cloud resource selection (Jrad et al. 2015; Ngan and Kanagasabai 2012; Pawar et al. 2014), redistribution of cloud resources (Houidi et al. 2011; Mechtri et al. 2013; Qiu et al. 2015), and a holistic toolkit for the entire CSB service life cycle (Ferrer et al. 2012).

For cloud resource selection, Ngan and Kanagasabai (2012) develop a novel OWL-S based semantic cloud service discovery and selection system. The system takes into account complex constraints and semantic matching. Jrad et al. (2015) develop a utility-based, dynamic and flexible matching algorithm capable of maximising the users' profits. Pawar et al. (2014)'s work is similar to the first two papers, but it has a development focus on trust and security in the CSB environment.

For cloud service redistribution, Mechtri et al. (2013) develop a software defined network (SDN) controller that controls connectivity between distributed resources received from multiple cloud vendors in a CSB environment. Houidi et al. (2011) develop an application to instantiate the inter-cloud links for cloud resource splitting among multi-cloud resources. The aim is to minimise overall cost for customers. Qiu et al. (2015) is similar to Houidi et al. (2011), especially on the profit maximisation part, but Qiu et al. (2015) achieve it through energy efficiency, i.e., green computing for profit and environmental wellbeing.

The work from Ferrer et al. (2012) is distinctive from the others. They develop a CSB management toolkit for the entire CSB service life cycle. This tool covers service construction, deployment, and operation stages, and take into account fundamental CSB requirements like trust, risk, eco-efficiency and cost.

There is limited research at this moment on the CSB development stage as the majority of research efforts are oriented toward the design stage. We believe that more research on the development stage will follow once researchers are satisfied with research at the design stage. It is in the best interest of the CSB community not to further delay any progress in the development stage, (and indeed the proceeding

deployment stage). We consider a CSB development cycle to be a iterative process with new ideas and models developed at the design stage feeding in to development and deployment and so on.

Deployment stage

Altogether, there are five papers in the deployment stage. They could be classified into three strands: resource selection (Amato and Venticinque 2013); resource distribution (Pawluk et al. 2012; Song et al. 2012; Tordsson et al. 2012) , and cloud quality testing (Kiran et al. 2014).

In the resource section group, Amato and Venticinque (2013) develop and evaluate a CSB, which focuses on automatic selection of cloud providers based on SLA and users' requirements. Next on the resource distribution, Pawluk et al. (2012) develop and test a CSB prototype for cloud resource distribution and runtime management based on customer's defined key performance indicators (KPIs). Tordsson et al. (2012) test a CSB architect and scheduling algorithms using a real case data. The results suggest that a multi cloud deployment provides a better performance, and a lower cost. Song et al. (2012) propose and evaluate a profit aware dynamic bidding (PADB) algorithm, which allocates cloud requests to multiple cloud service providers at the cheapest spot rate to maximise CSB's profits. Finally on cloud quality testing, Kiran et al. (2014) are looking to develop a strategy for automated SaaS testing in a CSB environment. They argue that more and more testing will be required in the CSB environment as quality of service becomes a demand factor in any cloud service operation.

The deployment stage, which involves several software-testing activities, is a significant stage in a software development cycle. A software product like a CSB is complex and can be opaque for error detection through a simple sight inspection, e.g., by inspecting at a software storage device (Galin 2004, p. 6). Thus, testing is a key activity in the software development cycle. Testing is simply defined as a "*process of executing a program with an intent of finding errors*" (Myers et al. 2011). It ensures a satisfactory software quality, which is likely to promote customer satisfaction and lower maintenance cost (Rafi et al. 2012). Rigorously tested software stands a better chance of success in long-term adoption. Similarly, testing relates significantly to requirements set out in the design stage including interoperability, SLAs and so on. Provided with a limited number of research papers on this topic, along with its potential to contribute to an overall CSB success, we call for more research contribution in this stage.

Management stage

Papers in the management stage deal with business aspects in software design. We classified this group of papers into two categories – operational and strategic – similar to the design stage.

Papers that provide operational direction for CSB management are minimal when compared to the strategic group. They present a toolkit that will help a CSB manage their cloud services with customers and providers. Rogers and Cliff (2012) compute profitability for the CSB business model. They conclude that the CSB business model is a viable business option. Laleh et al. (2015) propose an initial framework to improve service provisioning in the SaaS environment. They adopt the term *'context awareness'* to represent four attributes in their CSB framework design: specification management; service recommender; service discovery; and context fusion and observation. Barker et al. (2015) propose a Broker-as-a-service framework (BaaS) to enhance operations in a multiple-cloud environment. Four components proposed in BaaS are: high-lever user requirement; application specific brokering; lightweight cloud benchmarking; and dynamic cloud management.

Papers on the strategic direction for CSB management are looking into the future direction that a CSB should progress. A paper (Bratanis et al. 2013) is oriented toward CSB research while the remaining papers are contributing new ideas to promote CSB adoption. For the research-oriented paper, Bratanis et al. (2013) propose seven research millstones to develop a platform-independent CSB with an aim for continuous quality assurance and optimisation. The seven milestones are: (1) a set of requirements that CSB should address, (2) a conceptual CSB architect with core competences and functions, (3) tools and methods for a platform-free CSB, (4) methods and mechanisms for continuous cloud service governance and quality control, (5) methods and mechanisms for enabling continuous cloud service failure prevention and recovery, (6) methods and mechanisms for continuous optimisation of cloud service delivery, and (7) a framework validation through case study. The remaining papers propose new ideas into CSB with an aim to promote CSB adoption at the enterprise level. Some capabilities are believed to strengthen CSB competitive advantage hence CSB adoption. These capabilities are: service governance; quality assurance;

trust (Bellamy 2013); and change management (Grivas et al. 2010). New business models through/for CSB are presented. Stamas et al. (2014) illustrate business case on how a CSB transformed Mohawk, an 80-year-old paper mill business, into a global full-fletch media solutions company. Kuada and Olesen (2011) propose a social network approach to CSB. This model operates under the term *Opportunistic Cloud Computing Service* (OCCS), which is in essential the CSB model minus a business agreement. The new model requires enterprises to share and manage their cloud resources, without entering into any business agreement. Despite the success of UK's G-cloud project discussed earlier, Bellamy (2013) is the only research working on CSB in the public sector; the others focus exclusively on the private sector.

There is a clear unbalanced research profile in the management stage. A higher concentration of research gears toward strategic directions and business models. For a new stream of research like CSB, this might be a good sign since this strategic direction may set a direction for the entire CSB community moving forward. However, to support a viable CSB operation in the long run, more research in the CSB operational arena is required. Research that integrate multiple concerns into a framework like Barker et al. (2015; Laleh et al. (2015) are a satisfactory starting point. However, a holistic CSB management toolkit, which considers strategic and operational issues simultaneously, should be encouraged. In addition, there should be more research on the public sector.

Conclusion

This paper provides a systematic literature review of the cloud service brokerage (CSB) topic within the academic community to (1) provide an overview of the CSB research, and (2) give suggestions on how the CSB research should proceed. We have compiled 41 relevant papers on the topic from 2009 to-2015 from the Information Systems and Computer Science disciplines. Our analysis of the literature is broken down into two levels: the descriptive analysis and the software development lifecycle analysis.

Our descriptive analysis reveals that the academic interest first emerged in 2009 but did not pick up continuously until 2012. There is a slight decrease in publication count in 2015. This is unlikely to indicate a declining interest on the CSB topic in the future. Discipline-wise, more than 83 per cent of the 41 papers identified are from the Computer Science discipline. This is problematic in the long run since a successful CSB paradigm would require insights from the Information Systems discipline, especially on how a technological system, like a CSB, might interact with the social system, e.g., enterprise adoption of CSB. Thus, we call for more research contributions on the CSB topic from the Information Systems community.

From a holistic viewpoint, the software development lifecycle analysis reveals a heavier research interest on the design stage. There are little research efforts in the deployment, development and management stages. We call for more research contributions on these stages, as we believe that the CSB research paradigm will only prosper through a balanced research endeavour in the lifecycle. Considering each stage of the software development cycle one by one, we find that research efforts in the design stages is heavily oriented toward operational issues around CSB design, which are technical oriented, e.g., user requirements and service level agreements. We call for more research focus on strategic issues in CSB design including combinations of operational with strategic issues. Research on the development stage is minimal. We urge CSB researchers not to further delay research at the development stage. Ideas generated in the design stage should be coded and tested for further improvements. There are five research papers in the deployment stage, which consider software-testing activities in three areas: resource selection, resource distribution, and cloud quality testing. More and more testing will be required in the future due to an increased concern for quality, driven by the emphasis of design stage research, thus it is time for CSB researchers to look into this issue. Lastly on the management stage, there are lack of research efforts on the operational stream for CSB management, i.e., day-to-day management of CSBs and indeed specific research on CSBs for public sector. The majority of papers in this stage are looking into business capabilities. We call for a holistic CSB toolkit that considers issues at the strategic and operational levels simultaneously, and a research focus on the public body. We believe that research result at each stage is feeding into one another; for example, a successful CSB design based on idea in the management stage is likely to lead to an accomplished result in the development and deployment stages accordingly. Thus, no single step is the software development lifecycle is to be ignored.

This paper provides two key contributions to the research community. First, it provides an overview of the CSB research community on how they are evolving. To the best of our knowledge, a systematic review, like

this, is the first of its kind on the emerging CSB topic. Second, it highlights areas that future research contributions in the CSB are required, both in Computer Science and Information Systems. Our suggestions for research contributions are based on the idea that every key aspect in the software development lifecycle is equally important to a successful CSB paradigm. CSB is clearly a complex software system, in which insights from other disciplines apart from Computer Science and Information Systems, such as economics (e.g. profit maximisation), and law (e.g., service level agreement, and territorial jurisdiction) are required. Therefore, it will be useful for future research efforts to combine insights from these disciplines into the CSB research agenda.

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