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Literature Review on Container-Based Virtualization Technologies

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Abstract Container-based virtualization (CBV) has become a cornerstone of modern IT infrastructure, with technologies such as Docker and Kubernetes dominating application packaging and orchestration, respectively. Despite the proliferation of research in this domain, no existing secondary study systematically maps CBV technologies across both IT domains and academic dimensions (education, research, and outreach). This paper presents a Systematic Mapping Study (SMS) of 226 primary studies published between 2022 and 2024, identified through a hybrid strategy combining database searches across five digital libraries and forward/backward snowballing. Studies were classified using 11 IT domains and three academic dimensions, assessed through three quality indices (CVI, SCI, IRRQ), and organized into a novel dual-axis taxonomic structure. The results reveal a marked concentration around Docker (41.6%) and Kubernetes (29.6%), a dominance of IT Infrastructure as a research domain (75.66%), and a significant underrepresentation of education (11.06%) and outreach (5.88%) in the CBV literature. Six concrete research gaps are identified, including the need for alternative runtime evaluation, orchestration beyond Kubernetes, and empirical studies on CBV in educational contexts. The proposed taxonomy and identified gaps provide a structured foundation for researchers, educators, and practitioners navigating the rapidly expanding CBV landscape.

Keywords: Container-based virtualization, Systematic mapping study, Docker, Kubernetes, Cloud computing, Software engineering

1 Introduction

Cloud computing has established itself as a transformative paradigm in contemporary information technology, enabling scalable and resilient solutions through on-demand resource provisioning [Segun-Falade et al., 2024]. Among the foundational technologies supporting this paradigm, container-based virtualization (CBV) has gained significant traction due to its lightweight footprint, portability, and rapid deployment capabilities [Almoudane, 2025]. Unlike full virtualization, which emulates complete hardware environments, containers share the host operating system kernel while maintaining application isolation, resulting in substantially lower overhead [Kozhirbayev and Sinnott, 2017]. These properties have made CBV a preferred approach for deploying, managing, and scaling applications across distributed environments, facilitating continuous integration, agile development, and microservices architectures [Clement, 2025].

Within the CBV ecosystem, Docker has emerged as the *de facto* standard for container creation and management, while Kubernetes dominates container orchestration. However, the rapid evolution of this field has produced a diverse landscape of alternative technologies—including Podman, Singularity, LXC, gVisor, and Kata Containers—each optimized for specific use cases such as rootless operation, high-performance computing, or enhanced security [Baresi et al., 2024b]. This technological diversification necessitates a systematic analysis to identify which technologies are adopted in which contexts and to what extent.

Beyond industrial applications, CBV technologies have increasingly permeated academic settings, supporting education through reproducible laboratory environments, enabling research through portable computational pipelines, and facilitating outreach through accessible cloud-based platforms. However, the extent and nature of this academic adoption remain poorly characterized in the literature.

This paper presents a Systematic Mapping Study (SMS) that addresses this gap by mapping 226 primary studies (2022–2024) across 11 IT domains and three academic dimensions (education, research, outreach). The study contributes: *(1)* a comprehensive, reproducible mapping of the CBV research landscape; *(2)* a novel dual-axis taxonomic structure linking technologies to both IT domains and academic impact; and *(3)* the identification of six concrete research gaps with actionable future directions.

The remainder of this paper is organized as follows: Section 2 outlines the study motivation. Section 3 critically analyzes related works. Section 4 describes the SMS methodology. Section 5 addresses threats to validity. Section 6 presents the analysis, discussion, and future research directions. Section 7 concludes the paper.

2 Motivation

The adoption of cloud computing has produced a wide range of solutions based on container-based virtualization Hassan et al. [2022]. However, as noted by multiple authors Waseem et al. [2024]; Vhatkar and Bhole [2022]; Kithulwatta et al. [2022a], the literature remains fragmented: the high volume of publications makes it difficult to identify clear usage patterns, benefits, and limitations across application domains.

This study is motivated by three specific needs. First, there is no existing secondary study that simultaneously maps CBV technologies across multiple IT domains *and* academic dimensions (education, research, outreach). Second, the rapid proliferation of container technologies beyond Docker—including Podman, Singularity, gVisor, and others—requires a systematic assessment of their adoption and research coverage. Third, the potential of CBV as a transversal tool for academic activities (reproducible research, portable teaching environments, accessible outreach platforms) has not been systematically evaluated.

The expected outcomes include: *(i)* a comprehensive map of CBV research trends across 11 IT domains; *(ii)* a classification of studies by their contribution to education, research, and outreach; and *(iii)* a taxonomic structure that can guide technological decision-making for researchers, educators, and practitioners.

3 Related Works

Several secondary studies have addressed container-based virtualization (CBV) from different perspectives. To position the contribution of the present SMS, this section critically analyzes the existing literature organized by three dimensions: *(i)* scope and coverage, *(ii)* methodology, and *(iii)* domain focus. Table 1 synthesizes this comparative analysis.

Prior reviews differ substantially in the breadth of technologies and application contexts examined. Bentaleb et al. [2022b] and Sepúlveda-Rodríguez et al. [2022] both propose taxonomic classifications of virtualization technologies; however, neither extends its analysis to the academic dimension (education, research, and outreach). Similarly, Malhotra et al. [2024b] provide a systematic literature review focused exclusively on container lifecycle management—image detection, scheduling, security, and performance—without mapping these concerns to specific IT domains or educational contexts. In contrast, Kaiser et al. [2022b, 2023b] narrow their scope to ARM-compatible container technologies, prioritizing energy efficiency and edge computing performance. While valuable, this architectural focus limits the generalizability of their findings across the full spectrum of CBV use cases.

Among the related works, only Naydenov and Ruseva [2023a] adopt a systematic mapping methodology, focusing on container orchestration architectures in cloud computing. Their categorization scheme, however, is restricted to orchestration and does not encompass runtime technologies, academic applications, or cross-domain analysis. The remaining studies employ narrative or traditional review methods, which—while informative—lack the structured, reproducible search protocols and quality assessment mechanisms that characterize an SMS Kitchenham et al. [2010].

A common limitation across all reviewed studies is the absence of a cross-cutting analysis that maps CBV technologies to both IT domains (e.g., software development, HPC, security, AI) and academic dimensions simultaneously. None of the existing works: *(a)* provides a comprehensive mapping of CBV across multiple IT domains; *(b)* examines the role of containerization in education and outreach; or *(c)* offers a taxonomic structure linking technologies, domains, and academic impact.

Study	Type	Multi-domain	Acad.	Taxon.	Reprod.
Bentaleb et al. [2022b]	Review	✗	✗	✓	✗
Kaiser et al. [2022b]	Review	✗	✗	✗	✗
Sepúlveda-Rodríguez et al. [2022]	Review	✗	✗	✓	✗
Kaiser et al. [2023b]	Review	✗	✗	✗	✗
Naydenov and Ruseva [2023a]	SMS	✗	✗	✓	Partial
Malhotra et al. [2024b]	SLR	✗	✗	✗	Partial
This study	**SMS**	✓	✓	✓	✓

Table 1. Comparative analysis of related secondary studies. Multi-domain: covers multiple IT domains; Acad.: includes academic dimensions; Taxon.: proposes a taxonomy; Reprod.: provides reproducibility artifacts.

This SMS addresses these gaps by providing: *(1)* a systematic, reproducible mapping of 226 primary studies across 11 IT domains; *(2)* a novel classification linking CBV technologies to education, research, and outreach; and *(3)* a taxonomic structure that integrates technological and academic perspectives, enabling researchers and practitioners to identify both consolidated areas and under-explored research opportunities.

4 Review Method

This study follows a Systematic Mapping Study (SMS) methodology, guided by the established frameworks of Petersen et al. Runeson and Höst [2009] and Kitchenham and Charters Kitchenham et al. [2010]. Unlike a Systematic Literature Review (SLR), which aims to synthesize evidence on a specific question, an SMS provides a broad overview of a research area by classifying and categorizing existing literature Runeson and Höst [2009]. Following Mourao et al. [2017] and Nguyen et al. [2015], a hybrid search approach was adopted, combining automated database queries with manual snowballing to maximize coverage.

To ensure transparency and reproducibility, the SMS-Builder tool Candela-Uribe et al. [2022] was employed throughout the process for study identification, classification, data extraction, and quality assessment. The SMS process comprises six stages: (1) planning, (2) study search, (3) quality assessment, (4) data extraction, (5) study classification, and (6) results. Figure 1 illustrates these stages.

4.1 Planning

The planning stage established the research goals, questions, metrics, classification criteria, and quality assessment indices. Figure 2 summarizes the components of this stage.

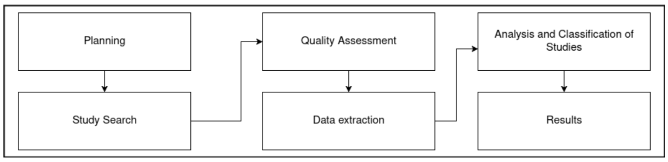

Figure 1. Stages of the SMS process

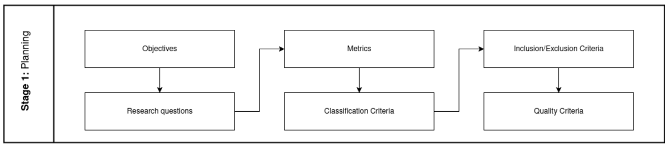

Figure 2. Composition of the planning stage

4.1.1 Study Goals

Two overarching goals were defined to guide this SMS, as presented in Table 2.

Goal	Description
G1	Identify studies related to CBV in education, research, and outreach.
G2	Classify studies related to CBV across IT domains, including software development, computational thinking, parallel computing, data analysis, artificial intelligence, computer networks, IT infrastructure, HPC, security, cloud computing, and blockchain.

Table 2. Goals of the study

4.1.2 Research Questions

The research questions were formulated using the GQM (*Goal Question Metric*) framework Needleman [2002] and the PICOC model Petticrew and Roberts [2008], which structures the population, intervention, comparison, outcome, and context of the study (Table 4). Two research questions were derived, as detailed in Table 3.

4.1.3 Metrics

Quantitative metrics were defined to measure the distribution of studies across the classification structure (Table 6). The search period was restricted to 2022–2024 to ensure currency.

Aspect	Description
Population	Studies related to CBV applied across IT domains, with emphasis on education, research, and outreach.
Intervention	Identification and classification of CBV studies within established IT domains.
Comparison	1. Comparison of CBV projects by reported success rates across IT domains. 2. Analysis of CBV impact on academic activities relative to alternative solutions.
Outcome	Classification structure mapping CBV studies to IT domains and academic dimensions.
Context	Education, research, and outreach contexts adopting CBV technologies.

Table 4. PICOC model specification

4.1.4 Research Topics

Based on the research questions and PICOC model, four research topics were defined: *Container-based virtualization*, *Education*, *Research*, and *Industry*. These topics were further refined through the IT domains identified as relevant to the study scope.

4.1.5 Inclusion and Exclusion Criteria

Table 5 presents the inclusion and exclusion criteria. The three-year window (2022–2024) balances currency with sufficient volume. Both journal articles and conference proceedings were included to capture the full publication landscape in this rapidly evolving field.

Metric	Description
M1	Number of studies identified per IT domain.
M2	Number of studies classified under education.
M3	Number of studies classified under research.
M4	Number of studies classified under outreach.

Table 6. Metrics defined for the analysis

4.1.6 Quality Assessment Criteria

Three quality indices were defined to evaluate the relevance and rigor of the selected studies.

Content Validity Index (CVI). The CVI assesses the degree to which each study aligns with the SMS objectives, adapted from established content validity methodology Almanasreh et al. [2019]; YAGHMAEI [2003]. Each study was independently rated by K evaluators (where K is odd, to prevent ties) on a scale from 0 (no relevance) to 5 (high relevance). Following the proportion-based CVI approach Almanasreh et al. [2019], we define the item-level CVI (I-CVI) as the proportion of evaluators who rate a study above a relevance threshold t:

$$\text{I-CVI} = \frac{n_t}{K} \tag{1}$$

where n_t is the number of evaluators assigning a score $\geq t$ (with $t = 3$ adopted in this study), and K is the total number of evaluators. An I-CVI ≥ 0.78 indicates acceptable content validity Almanasreh et al. [2019]. For aggregation across the study corpus, the Scale-level CVI based on the average method (S-CVI/Ave) is computed as the mean of all I-CVI values.

Scientific Citation Index (SCI). The SCI captures citation-normalized impact relative to publication recency. For a study with C citations accumulated between 2022 and 2024, published A years before the extraction date:

$$\text{SCI} = \frac{C}{A} \tag{2}$$

This normalization ensures that recently published studies with emerging citation counts are not penalized relative to older, more-cited works.

Index of Relationship to Research Questions (IRRQ). The IRRQ quantifies the coverage of a study with respect to the defined research questions. Given $Q = 2$ research

Goal	Question	Description	Motivation
G1	Q1	Which studies related to container-based virtualization (CBV) technologies contribute to education, research, and outreach?	CBV enables environment reproducibility, facilitating the transfer of IT solutions across contexts. Understanding its academic penetration can stimulate cross-domain innovation.
G2	Q2	Which primary studies related to CBV technologies contribute to IT domains such as software development, HPC, AI, security, cloud computing, and others?	The goal is to provide a structured overview of CBV adoption across IT domains, enabling researchers and practitioners to identify trends without requiring exhaustive primary analysis.

Table 3. Research questions and their motivation

Category	Inclusion	Exclusion
Screening field	Abstract	—
Publication type	Journal articles and conference proceedings	Theses, book chapters, grey literature
Discipline	Computer Science, Information Technology, Engineering, IT Management	Disciplines unrelated to virtualization or computing
Time period	2022–2024	Before 2022
Language	English	Non-English publications

Table 5. Inclusion and exclusion criteria

questions in this SMS, the IRRQ for a study addressing n questions is:

$$\text{IRRQ} = \frac{n}{Q} \tag{3}$$

where $n \in \{0, 1, 2\}$ and $Q = 2$. Thus, IRRQ $\in \{0, 0.5, 1\}$, where 1 indicates full coverage of both research questions. This index enables identification of studies with broad versus narrow thematic relevance.

4.2 Stage 2: Study Search

A hybrid search strategy combining database queries and snowballing was employed. Figure 3 summarizes the components of this stage.

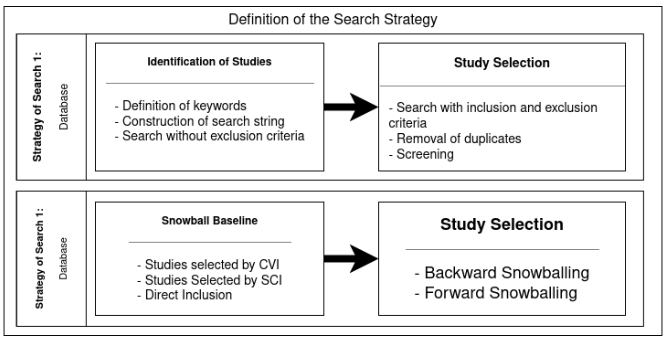

Figure 3. Composition of the study search stage

4.2.1 Defining the Search Strategy

Two complementary strategies were combined. The first involves automated search string execution in academic databases Jalali and Wohlin [2012]. The second, snowballing, identifies additional studies through backward (reference tracking) and forward (citation tracking) analysis of a seed set Jalali and Wohlin [2012]; Goodman [1961].

4.2.2 Search Strategy 1: Databases

This strategy comprises two phases: *Study Identification* (search string construction and execution) and *Study Selection* (criteria-based refinement).

- **Study Identification:** Five databases were queried: *ACM*, *IEEE Xplore*, *Springer*, *Science Direct*, and *Taylor & Francis*. Keywords were derived from the PICOC model (Table 7) and expanded with synonyms (Table 8). Boolean operators (*AND*, *OR*) and exact-phrase matching were used to construct database-specific search strings through iterative pilot searches. The complete search strings are available via the reproducibility artifacts (Section 4.6.3).
  Execution across all databases yielded **6,530** preliminary results, with Springer contributing the largest share (**4,562**; 69.8%). Table 9 details the distribution.

Aspect	Description
Population	CBV, IT Domains, Education, Research, Outreach
Intervention	Identification, Classification
Comparison	Success rate, Evidence of use
Output	Classification of CBV studies per IT domain
Context	Education, Research, Outreach

Table 7. Keywords identified using the PICOC model

Keyword	Synonyms
Container-based virtualization	Application virtualization, Docker, Lightweight Virtualization
Education	Education System, Education Development, Higher Education
Research	Research Group, Research Proposal
Industry	IT Services, Technology Infrastructure, Cloud Computing

Table 8. Keywords for database search

- **Study Selection:** Application of inclusion and exclusion criteria reduced the set to **976** studies (Table 10), with Springer maintaining the largest contribution (**592**; 60.65%). After removing **274** duplicates, a screening process (title, abstract, and keyword review) excluded **593** irrelevant studies, yielding **110** selected studies from the database strategy. Figure 4 summarizes this process.

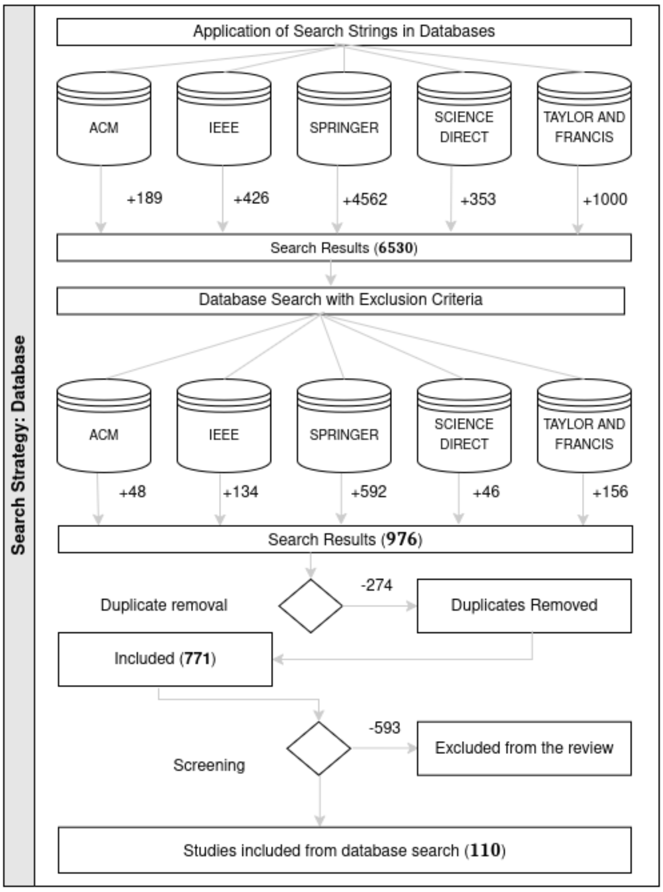

Figure 4. Summary of activities and results obtained in the database search strategy

4.2.3 Search Strategy 2: Snowballing

The snowballing search strategy began with the identification of the base set of articles. This base set is obtained from Search Strategy 1. The procedure consisted of two phases:

The first phase, called *Base Line Construction*, aims to establish the articles on which a citation and reference analysis will be performed. To form this initial set of studies, several criteria were applied, including the CVI *(Content Value Index)*, the SCI *(Study Citation Index)*, and the direct inclusion criterion. The second phase, called *Study Selection*, focuses on the analysis of references *(Backward Snowballing)* and citations *(Forward Snowballing)* corresponding to each article Wohlin [2014].

The base line construction started from the **110** articles obtained in the database search strategy. From this set, **25** articles were selected using the SCI quality criterion. The choice of this criterion is based on the fact that it does not depend on the authors' assessment, but rather on the number of citations received by each article, which constitutes an objective indicator of academic relevance. The result of this process was a total of **25** articles selected for the base line. The selection was made through a citation frequency analysis, from which the first quartile **(Q1)** corresponding to the most cited articles was extracted. As part of the SMS process, studies can also be incorporated through direct inclusion. This procedure consists of adding an article previously known by the authors, without it coming directly from a database. This approach provides flexibility to the search process as it allows integrating works considered relevant by the authors for the research objective. In this case, one article was incorporated through direct inclusion, bringing the total to **26** articles in the base line.

After the base line construction, the reference analysis was performed, which allowed identifying a total of **495** new articles. The forward search process was conducted using Google Scholar, which provides information on the number of citations for each article, following the practices described in Ali et al. [2019]. Regarding the backward search, **87** additional articles were obtained.

14 duplicate articles were removed from the backward and forward search results. Subsequently, the *Screening* process was applied again, which, as in the previous phase, consisted of reviewing the title, abstract, and keywords of each work. This procedure reduced the set to **116** articles selected through the snowballing search strategy. Figure 5 presents a summary of the process followed in this search strategy.

4.2.4 Results of the Study Search

The combined search yielded **226** primary studies: **110** from databases, **115** from snowballing, and **1** through direct inclusion. The near-equal split between strategies (Table 11) confirms the complementarity of the hybrid approach.

Strategy	Studies	%
Databases	110	48.67%
Snowballing	115	50.88%
Direct Inclusion	1	0.44%
Total	**226**	**100%**

Table 11. Results of the study search

4.3 Stage 3: Quality Assessment

Although quality assessment is not mandatory in an SMS Ali et al. [2019], incorporating it strengthens the rigor of the mapping and brings it closer to a systematic review Wohlin [2014]. Three complementary indices—CVI, SCI, and IRRQ—were applied to evaluate study relevance.

4.3.1 Content Validity Assessment (CVI)

Each study was independently rated by an odd number of evaluators ($K \geq 3$) on a 0–5 relevance scale. The proportion-based I-CVI (Equation 1) was computed for each study, and studies with I-CVI ≥ 0.78 were considered to have acceptable content validity. Two assessment rounds were conducted: the first during baseline construction for snowballing (Section 4.2.4), and the second after all 226 studies were identified, with results reported in Section Study Classification.

Criterion	ACM	IEEE	Science Direct	Springer	Taylor and Francis
Search results using keywords only	189	426	4562	353	1000
Contribution percentage	2.89%	6.52%	69.86%	5.4%	15.31%

Table 9. Search results per database using keywords

Criterion	ACM	IEEE	Science Direct	Springer	Taylor and Francis
Search results after applying keywords only	48	134	46	592	156
Contribution percentage	4.91%	13.72%	4.71%	60.65%	15.98%

Table 10. Search results per database using keywords after applying inclusion/exclusion criteria

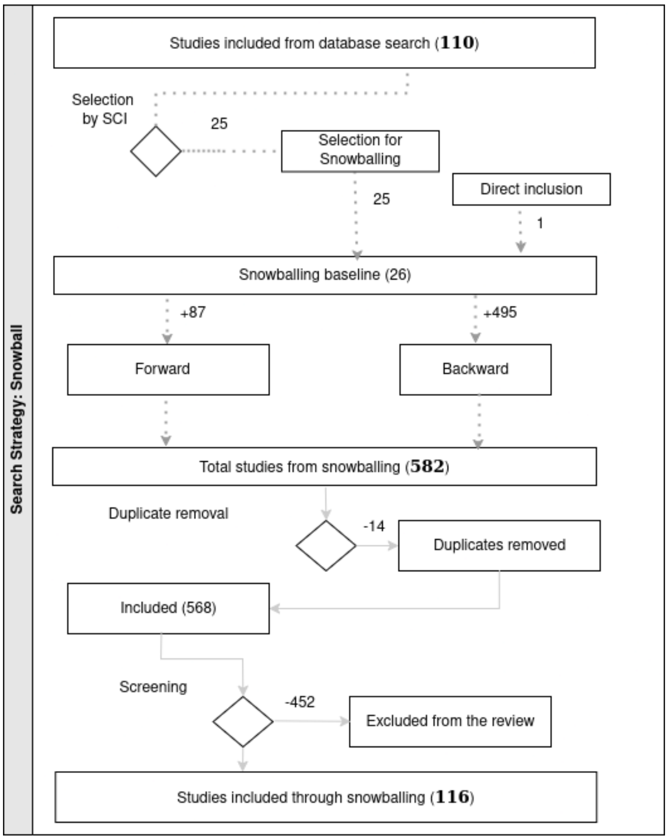

Figure 5. Summary of the snowballing search strategy

4.3.2 Citation-Based Quality Assessment (SCI)

The SCI (Equation 2) was computed using citation data from Google Scholar and the SMS-Builder tool Candela-Uribe et al. [2020]. A frequency analysis identified the top quartile (Q1) of studies by SCI, representing those with the highest citation-normalized impact.

4.3.3 Research Question Coverage Assessment (IRRQ)

The IRRQ (Equation 3) was computed for each study based on its thematic alignment with Q1 and Q2, as determined through the classification process. Studies with IRRQ $= 1$ (addressing both research questions) were identified through frequency analysis as the most thematically comprehensive.

4.4 Stage 4: Data Extraction

After completing study search and quality assessment, **226** primary studies were identified and labeled SPS001 through SPS226. The complete list is provided in Table 12.

4.5 Stage 5: Study Classification

The SPS were classified using the topics defined during planning (Table 13). A single SPS may be associated with multiple topics; for example, SPS069 is classified under IT Infrastructure, Security, Cloud Computing, and Research. This multi-label approach reflects the interdisciplinary nature of CBV research and enables cross-domain analysis.

Following classification, each SPS was evaluated using the CVI, SCI, and IRRQ quality indices. Tables 14, 15, and 16 present the top-quartile studies for each index, disaggregated by topic and year.

4.6 Stage 6: Results

This section presents and interprets the findings from the SMS, organized in three parts: (1) an overview of the SPS corpus with source and temporal analysis, (2) a technology and domain distribution analysis with interpretation of observed trends, and (3) a keyword co-occurrence analysis.

4.6.1 Overview of the SPS Corpus

The SMS identified **226** selected primary studies (SPS), listed in Table 12. The following subsections analyze the distribution of these studies across sources, technologies, academic dimensions, and quality indices.

Source and strategy distribution. Table 17 presents the classification of CBV technologies by academic dimension. Docker dominates across education, research, and outreach, accounting for **100** SPS (44.24%). This predominance reflects Docker's mature ecosystem, extensive documentation, and low barrier to entry, which collectively facilitate adoption in academic contexts where ease of deployment is prioritized over specialized performance characteristics.

Table 18 maps IT domains to academic dimensions. IT Infrastructure is the most represented domain, with **171** SPS (75.66%), indicating that containerization research remains strongly anchored to infrastructure-level concerns such as deployment, scaling, and resource management.

ID	Ref	ID	Ref
SPS001	Pastor-Galindo et al.	SPS002	Moysiadis et al.
SPS003	Malviya and Dwivedi	SPS004	Šimon et al.
SPS005	Yaory and Manuaba	SPS006	Kamieniarz and Mazurczyk
SPS007	Voulgaris et al.	SPS008	Nakarmi et al.
SPS009	Chen et al.	SPS010	Betz et al.
SPS011	Xi et al.	SPS012	Li et al.
SPS013	Madi and Esteves-Verissimo	SPS014	Wang and Li
SPS015	Raj	SPS016	Modey et al.
SPS017	Yang and Dai	SPS018	Wu et al.
SPS019	Bracke et al.	SPS020	Abas et al.
SPS021	Fischer et al.	SPS022	Li et al.
SPS023	Deng et al.	SPS024	Yin et al.
SPS025	Malhotra et al.	SPS026	Yuan and Liao
SPS027	González-Abad et al.	SPS028	Ruiz Ródenas et al.
SPS029	Ebrahimpour et al.	SPS030	Ye et al.
SPS031	Liagkou et al.	SPS032	Baresi et al.
SPS033	Ghorbian and Ghobaei-Arani	SPS034	Aktolga et al.
SPS035	Joraviya et al.	SPS036	Nakakaze et al.
SPS037	Soderi et al.	SPS038	Qian
SPS039	Galantino et al.	SPS040	Aldiabat et al.
SPS041	Kumar and Kaur	SPS042	Aung et al.
SPS043	Dimova et al.	SPS044	Azuma et al.
SPS045	Ndigande et al.	SPS046	Husain et al.
SPS047	Yarmilko et al.	SPS048	de Oliveira Filho et al.
SPS049	Ajith et al.	SPS050	Timonen et al.
SPS051	Kotenko et al.	SPS052	Silva et al.
SPS053	Hettiarachchi et al.	SPS054	Fava et al.
SPS055	Savitha et al.	SPS056	Dogani et al.
SPS057	Purahong et al.	SPS058	Benzi et al.
SPS059	Chaurasia et al.	SPS060	Kaiser et al.
SPS061	Stojanović et al.	SPS062	Kanagachalam et al.
SPS063	Vaidya et al.	SPS064	Jolak et al.
SPS065	Hao et al.	SPS066	Blanco et al.
SPS067	Wang et al.	SPS068	Naydenov and Ruseva
SPS069	Ganne	SPS070	Raj et al.
SPS071	Rashid and Qasha	SPS072	Pavao et al.
SPS073	Zhang et al.	SPS074	Candemir and İncereis
SPS075	Choi et al.	SPS076	Pankowski and Powroźnik
SPS077	Moussa et al.	SPS078	Geng et al.
SPS079	Chen et al.	SPS080	Gao et al.
SPS081	Spahn et al.	SPS082	Zhang et al.
SPS083	Kaiser et al.	SPS084	Patra et al.
SPS085	Wu et al.	SPS086	VS et al.
SPS087	Waseem et al.	SPS088	Bentaleb et al.
SPS089	Malan	SPS090	Keller Tesser and Borin
SPS091	Kaur	SPS092	El Khairi et al.
SPS093	Choi et al.	SPS094	Alelyani et al.
SPS095	Joraviya et al.	SPS096	Nelson and Shoshitaishvili
SPS097	Zhou et al.	SPS098	Bentaleb et al.
SPS099	Kim et al.	SPS100	Saxena et al.
SPS101	Yu et al.	SPS102	Horchulhack et al.
SPS103	Chamoli and Mittal	SPS104	Sobieraj and Kotyński
SPS105	Patra et al.	SPS106	Gharaibeh et al.
SPS107	Dipta et al.	SPS108	Gu et al.
SPS109	Jeon et al.	SPS110	Roy et al.
SPS111	Karumudi et al.	SPS112	Barbie et al.
SPS113	Ramanathan et al.	SPS114	Lee et al.

Continues on the next page

Table 12 – continued

ID	Ref	ID	Ref
SPS115	Sedov and Lazarev	SPS116	Kostolny et al.
SPS117	Jang and Luo	SPS118	Flora and Antunes
SPS119	Ukene et al.	SPS120	Molnár et al.
SPS121	Dakić et al.	SPS122	Kaiser et al.
SPS123	Barletta et al.	SPS124	Rosa et al.
SPS125	Barros et al.	SPS126	Zeng et al.
SPS127	Gupta et al.	SPS128	Frasão et al.
SPS129	Gamess and Parajuli	SPS130	Alif and Munggaran
SPS131	Moric et al.	SPS132	Eroshkin et al.
SPS133	Singh et al.	SPS134	Kuity and Peddoju
SPS135	Narasimhulu et al.	SPS136	Entrialgo et al.
SPS137	Dogani et al.	SPS138	Lee et al.
SPS139	Ma et al.	SPS140	Kosińska et al.
SPS141	Zheng et al.	SPS142	Bellavista et al.
SPS143	Johansson et al.	SPS144	Carrión
SPS145	Carrión	SPS146	Botez et al.
SPS147	Haq et al.	SPS148	Dubey et al.
SPS149	Bannon	SPS150	Abbadini et al.
SPS151	Geetha et al.	SPS152	Fernalld et al.
SPS153	Mills et al.	SPS154	Han et al.
SPS155	Yang et al.	SPS156	Karmakar and Arri
SPS157	Mailewa et al.	SPS158	Barnawi et al.
SPS159	Pérez et al.	SPS160	Barletta et al.
SPS161	Zuppelli et al.	SPS162	Bhuiyan et al.
SPS163	Mondal et al.	SPS164	Mondal et al.
SPS165	Wong et al.	SPS166	Song et al.
SPS167	Bracke et al.	SPS168	Alamoush and Eichelberger
SPS169	Joshi et al.	SPS170	Kumar et al.
SPS171	Mthembu et al.	SPS172	Eng et al.
SPS173	Kurniawan et al.	SPS174	Melo et al.
SPS175	Widodo et al.	SPS176	Kithulwatta et al.
SPS177	Fu et al.	SPS178	Abdulah et al.
SPS179	Jeong et al.	SPS180	Gackstatter et al.
SPS181	Ersted Rasmussen et al.	SPS182	Xie et al.
SPS183	Lee et al.	SPS184	Karamzadeh and Shameli-Sendi
SPS185	Alyas et al.	SPS186	Mehran and Ulus
SPS187	Du et al.	SPS188	Xu et al.
SPS189	Al-Obaidi et al.	SPS190	Zehra et al.
SPS191	Haq et al.	SPS192	Saxena et al.
SPS193	Rajasekar et al.	SPS194	Thurimella et al.
SPS195	Al Qausar et al.	SPS196	Shrestha and Ray
SPS197	Agrawal and Singh	SPS198	Antonova et al.
SPS199	Burchart and Haake	SPS200	Mujkanovic et al.
SPS201	Hristev et al.	SPS202	Zhou et al.
SPS203	Yang et al.	SPS204	Jackson and Wurst
SPS205	Li et al.	SPS206	Ashari et al.
SPS207	Dobslaw et al.	SPS208	Rosmaninho et al.
SPS209	Álvarez et al.	SPS210	Wang et al.
SPS211	Amoiridis et al.	SPS212	Schmidt et al.
SPS213	Augustyn et al.	SPS214	Choi et al.
SPS215	Rodriguez et al.	SPS216	Kunekar et al.
SPS217	Shakya and Tripathi	SPS218	Arifiansyah et al.
SPS219	Kwon et al.	SPS220	Haresh et al.
SPS221	Malhotra et al.	SPS222	Kjorveziroski and Filiposka
SPS223	Kjorveziroski and Filiposka	SPS224	Li et al.
SPS225	Rosa et al.	SPS226	Kim et al.

Technology landscape analysis. Figure 6 shows the distribution of studies by source and strategy. Of the database-sourced studies (110 SPS), IEEE Xplore and ACM Digital Library jointly contribute 68.18%, reflecting the strong alignment of CBV research with computing-focused venues. The snowballing strategy (115 SPS) was dominated by forward snowballing (92.17%), suggesting that CBV is an expanding field where newer publications actively cite foundational works.

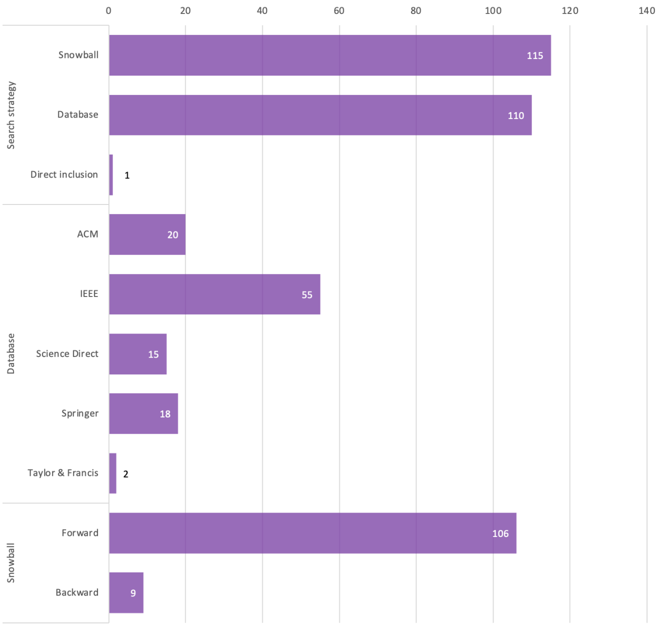

Figure 6. SPS by source and search strategy

Figure 7 reveals the distribution of container runtime technologies. Docker leads with **94** SPS, followed distantly by Podman (7), LXC and Containerd (4 each), and Singularity, runC, and gVisor (3 each). This concentration raises an important finding: *despite the growing ecosystem of alternative container runtimes designed for security (gVisor, Kata Containers), HPC (Singularity), and rootless operation (Podman), the research community remains heavily Docker-centric*. This gap between technological diversity and research coverage represents an opportunity for future studies to evaluate emerging runtimes in domains where Docker's limitations are well documented.

Figure 8 shows orchestrator distribution. Kubernetes dominates with **67** SPS, confirming its status as the *de facto* standard for container orchestration. Docker Swarm (9 SPS) and Apache Mesos (5 SPS) trail significantly. The marginal representation of alternatives such as OpenShift (2), Docker Compose (3), and cloud-native services (Amazon ECS/EKS, 1 each) suggests that *academic research has not yet systematically evaluated the trade-offs between Kubernetes and its alternatives*, particularly in edge computing, serverless, and resource-constrained environments where lighter orchestration solutions may be more appropriate.

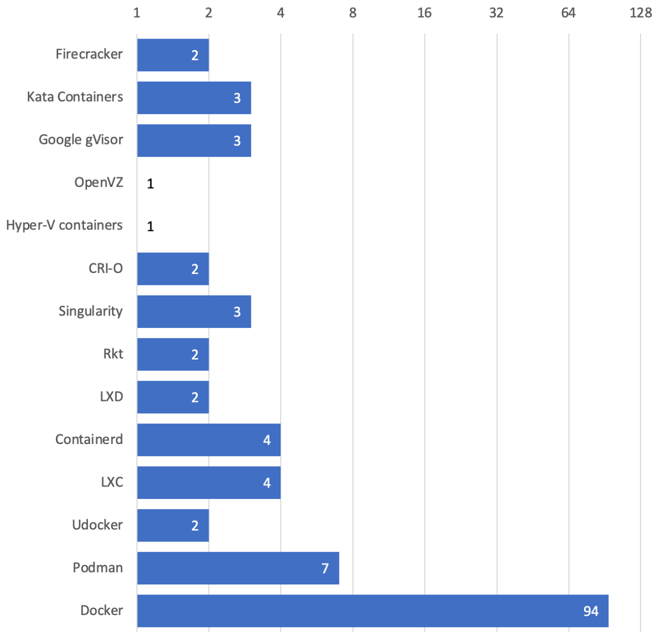

Figure 7. Distribution of container runtime technologies across SPS

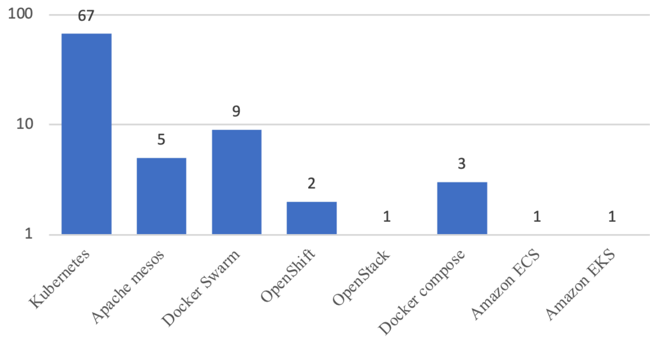

Figure 8. Distribution of orchestrator technologies across SPS

Academic dimension analysis. Figure 9 illustrates the intersection of studies across academic dimensions. Research dominates with **187** exclusive SPS, while Education (19 exclusive) and Outreach (8 exclusive) remain underrepresented. Notably, *no study simultaneously addresses all three dimensions*, revealing a significant fragmentation in academic production. Only 6 SPS bridge Research and Education, and 6 bridge Research and Outreach, with zero overlap between Education and Outreach. This finding suggests that the potential of CBV as a transversal tool linking teaching, research output, and societal impact remains largely unexplored.

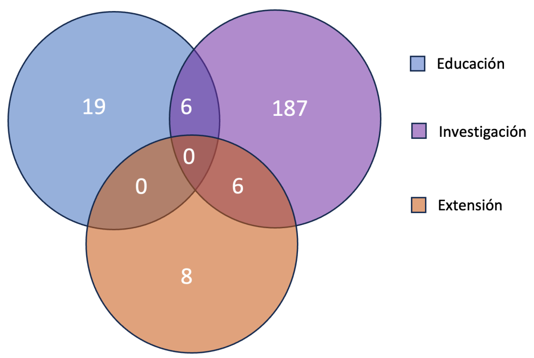

Figure 9. Venn diagram of SPS across academic dimensions

Topic and temporal distribution. Figure 10 shows topic distribution per research question. For Q1, Research accounts for 83.61% of studies, while Outreach represents only 5.88%—a disparity that underscores the limited penetration of containerization into community engagement and societal applications. For Q2, IT Infrastructure leads (41.28%), followed by Cloud Computing (14.37%), while Blockchain (0.76%) and Parallel Computing represent emerging but underexplored intersections with CBV.

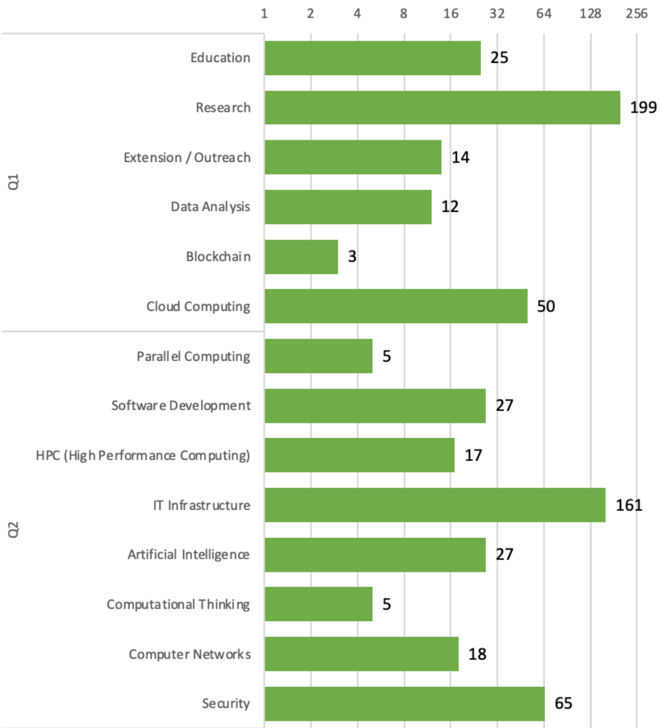

Figure 10. SPS distribution by research questions and topics

The temporal analysis (Figure 11) reveals sustained growth, from **49** SPS in 2022 to **107** in 2024 (a 118% cumulative increase). The sharpest growth occurred between 2023 and 2024 (+52.85%), coinciding with the maturation of Kubernetes-based cloud-native architectures and the proliferation of edge computing applications. The CVI index shows an upward trend (from 7 to 9, +28.57%), suggesting that more recent studies exhibit stronger alignment with the SMS objectives. The SCI index remains stable around 18, with a slight recovery in 2024 (+11.76% over 2023), while the IRRQ index exhibits sustained growth from 30 to 39 (+30% cumulative), indicating increasing thematic breadth in newer publications.

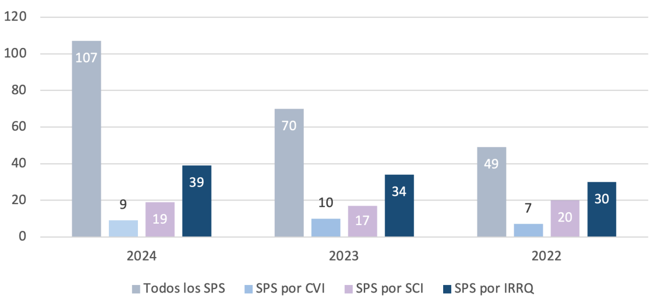

Figure 11. SPS by year and quality indices

Figure 12 presents the quality indices disaggregated by topic. IT Infrastructure not only has the highest volume (73 SPS, 43.71% of Q2) but also concentrates the highest-quality studies across all three indices, reinforcing its centrality to the CBV research landscape. The Outreach topic, with only 8 SPS (7.33% of Q1), represents the most significant gap identified in this mapping.

Figure 13 presents a cross-analysis of keywords. The term "*Container*" enables the identification of 57 SPS, while education-related keywords (*Learning*, *Cybersecurity education*) appear in only 2 SPS each—further evidence that the academic community has not yet developed a robust vocabulary linking CBV to educational and outreach applications.

Table 13. Classification of SPS studies by topic and year

RQ	Topics	2022	2023	2024
Q1	Research	SPS002, SPS003, SPS007, SPS013, SPS017, SPS023, SPS039, SPS041, SPS044, SPS053, SPS059, SPS062, SPS064, SPS069, SPS070, SPS071, SPS073, SPS077, SPS079, SPS080, SPS083, SPS085, SPS088, SPS092, SPS098, SPS099, SPS105, SPS137, SPS143, SPS144, SPS145, SPS146, SPS149, SPS154, SPS155, SPS157, SPS176, SPS177, SPS180, SPS182, SPS187, SPS191, SPS192	SPS004, SPS012, SPS015, SPS027, SPS029, SPS034, SPS046, SPS047, SPS055, SPS056, SPS057, SPS060, SPS066, SPS067, SPS068, SPS075, SPS076, SPS081, SPS084, SPS086, SPS090, SPS093, SPS094, SPS097, SPS103, SPS117, SPS119, SPS126, SPS127, SPS134, SPS135, SPS138, SPS150, SPS153, SPS159, SPS165, SPS166, SPS167, SPS171, SPS173, SPS174, SPS175, SPS179, SPS183, SPS185, SPS189, SPS195, SPS200, SPS201, SPS203, SPS205, SPS208, SPS209, SPS212, SPS220, SPS221, SPS222, SPS223, SPS225, SPS226	SPS001, SPS005, SPS006, SPS008, SPS009, SPS010, SPS011, SPS014, SPS016, SPS018, SPS019, SPS021, SPS022, SPS024, SPS025, SPS026, SPS028, SPS030, SPS032, SPS033, SPS035, SPS036, SPS040, SPS043, SPS045, SPS048, SPS049, SPS050, SPS051, SPS052, SPS054, SPS061, SPS065, SPS074, SPS082, SPS087, SPS091, SPS095, SPS100, SPS102, SPS104, SPS106, SPS107, SPS108, SPS109, SPS110, SPS111, SPS113, SPS118, SPS121, SPS122, SPS123, SPS124, SPS125, SPS128, SPS129, SPS130, SPS131, SPS132, SPS133, SPS136, SPS140, SPS141, SPS142, SPS147, SPS148, SPS151, SPS156, SPS158, SPS160, SPS161, SPS162, SPS164, SPS168, SPS169, SPS170, SPS172, SPS178, SPS184, SPS186, SPS188, SPS190, SPS193, SPS194, SPS196, SPS197, SPS198, SPS202, SPS210, SPS213, SPS214, SPS215, SPS216, SPS217, SPS219, SPS224
	Education	SPS038, SPS058, SPS101, SPS146, SPS187, SPS204	SPS020, SPS072, SPS075, SPS116, SPS120, SPS152, SPS206, SPS207, SPS218	SPS042, SPS089, SPS096, SPS115, SPS124, SPS139, SPS151, SPS163, SPS198, SPS199
	Outreach	SPS002, SPS031, SPS037, SPS099	SPS078, SPS112, SPS208, SPS220	SPS010, SPS063, SPS114, SPS181, SPS211, SPS213
Q2	Software development	SPS002, SPS037, SPS038, SPS044, SPS053, SPS058, SPS098, SPS101	SPS015, SPS078, SPS086, SPS120, SPS183, SPS195	SPS008, SPS010, SPS022, SPS028, SPS042, SPS043, SPS096, SPS100, SPS118, SPS133, SPS172, SPS215, SPS224
	Computational thinking	SPS187	SPS116	SPS042, SPS115, SPS198
	Parallel computing	SPS017	SPS020, SPS134, SPS223	

RQ	Topics	2022	2023	2024
	Data analysis	SPS037, SPS071, SPS157	SPS183, SPS209	SPS001, SPS005, SPS028, SPS045, SPS061, SPS082, SPS129
	Artificial intelligence	SPS023, SPS037, SPS053, SPS059, SPS073, SPS077, SPS080, SPS149, SPS154, SPS177	SPS027, SPS072, SPS078, SPS183, SPS209	SPS011, SPS030, SPS040, SPS051, SPS082, SPS095, SPS142, SPS148, SPS161, SPS169, SPS170, SPS181
	Computer networks	SPS105, SPS187	SPS046, SPS094, SPS103, SPS159	SPS010, SPS019, SPS048, SPS106, SPS110, SPS113, SPS132, SPS139, SPS164, SPS198, SPS216, SPS219
	IT infrastructure	SPS003, SPS007, SPS017, SPS023, SPS031, SPS037, SPS038, SPS039, SPS062, SPS069, SPS070, SPS073, SPS077, SPS079, SPS083, SPS085, SPS088, SPS092, SPS099, SPS105, SPS137, SPS143, SPS144, SPS145, SPS146, SPS149, SPS154, SPS155, SPS176, SPS177, SPS180, SPS182, SPS187, SPS204	SPS004, SPS012, SPS020, SPS027, SPS029, SPS034, SPS046, SPS047, SPS055, SPS056, SPS057, SPS060, SPS066, SPS067, SPS068, SPS075, SPS076, SPS078, SPS081, SPS084, SPS090, SPS094, SPS103, SPS112, SPS117, SPS119, SPS126, SPS134, SPS135, SPS150, SPS152, SPS159, SPS167, SPS171, SPS173, SPS174, SPS175, SPS179, SPS183, SPS185, SPS189, SPS200, SPS201, SPS205, SPS206, SPS207, SPS208, SPS212, SPS218, SPS220, SPS222, SPS223, SPS225	SPS009, SPS011, SPS014, SPS018, SPS019, SPS021, SPS024, SPS025, SPS026, SPS030, SPS032, SPS033, SPS036, SPS048, SPS049, SPS051, SPS052, SPS054, SPS074, SPS082, SPS087, SPS089, SPS091, SPS095, SPS096, SPS100, SPS102, SPS104, SPS106, SPS107, SPS109, SPS110, SPS111, SPS115, SPS121, SPS122, SPS123, SPS124, SPS125, SPS129, SPS130, SPS131, SPS132, SPS136, SPS140, SPS148, SPS151, SPS156, SPS160, SPS163, SPS164, SPS168, SPS169, SPS170, SPS172, SPS178, SPS181, SPS184, SPS186, SPS188, SPS190, SPS196, SPS197, SPS198, SPS199, SPS210, SPS211, SPS213, SPS214, SPS215, SPS216, SPS217, SPS219, SPS224
	HPC	SPS017, SPS041, SPS062, SPS083, SPS098	SPS027, SPS090, SPS134, SPS200	SPS008, SPS014, SPS018, SPS114, SPS121, SPS129, SPS178, SPS194
	Blockchain			SPS063
	Security	SPS013, SPS064, SPS069, SPS070, SPS079, SPS083, SPS092, SPS155, SPS157, SPS191, SPS192	SPS034, SPS047, SPS081, SPS086, SPS093, SPS094, SPS097, SPS119, SPS126, SPS127, SPS138, SPS150, SPS153, SPS165, SPS166, SPS175, SPS183, SPS189, SPS203, SPS221, SPS226	SPS001, SPS006, SPS009, SPS016, SPS022, SPS025, SPS035, SPS040, SPS043, SPS049, SPS050, SPS051, SPS065, SPS082, SPS108, SPS118, SPS125, SPS128, SPS129, SPS131, SPS141, SPS147, SPS156, SPS158, SPS160, SPS161, SPS162, SPS170, SPS188, SPS190, SPS193, SPS214, SPS219

RQ	Topics	2022	2023	2024
	Cloud computing	SPS002, SPS003, SPS031, SPS069, SPS070, SPS071, SPS079, SPS080, SPS085, SPS099, SPS137, SPS143, SPS146, SPS149, SPS177	SPS012, SPS015, SPS029, SPS055, SPS056, SPS084, SPS126, SPS173, SPS179, SPS185, SPS222	SPS018, SPS019, SPS025, SPS026, SPS030, SPS032, SPS033, SPS043, SPS045, SPS087, SPS091, SPS109, SPS111, SPS136, SPS163, SPS193, SPS194, SPS197, SPS202, SPS210, SPS213, SPS214, SPS216, SPS217

Table 14. Studies with the highest CVI index, classified by topics

RQ	Topics	2022	2023	2024
Q1	Research	SPS003, SPS007, SPS083, SPS145, SPS146	SPS068, SPS174	SPS032, SPS136, SPS151, SPS168
	Education	SPS038, SPS146	SPS152, SPS206	SPS089, SPS115, SPS151
Q2	Software Development	SPS038		
	Computational Thinking			SPS115
	Data Analysis	SPS037, SPS071, SPS157	SPS183, SPS209	SPS001, SPS005, SPS028, SPS045, SPS061, SPS082, SPS129
	IT Infrastructure	SPS003, SPS007, SPS038, SPS083, SPS145, SPS146	SPS068, SPS152, SPS174, SPS206	SPS032, SPS089, SPS115, SPS136, SPS151, SPS168
	HPC	SPS083		
	Security	SPS083		
	Cloud Computing	SPS003, SPS146		SPS032, SPS136

Table 15. Studies with the Highest SCI Index, Categorized by Topic

RQ	Topics	2022	2023	2024
Q1	Research	SPS003, SPS044, SPS064, SPS083, SPS092, SPS137, SPS143, SPS145, SPS157, SPS176, SPS187, SPS192	SPS027, SPS029, SPS126, SPS165, SPS173, SPS223	SPS028, SPS032, SPS033, SPS054, SPS140, SPS197, SPS215
	Education	SPS187	SPS020, SPS072	
Q2	Software development	SPS044		SPS028, SPS215
	Computational thinking	SPS187		
	Parallel computing		SPS020, SPS223	
	Data analysis	SPS157		SPS028
	Artificial intelligence		SPS027, SPS072	
	Computer networks	SPS187		
	IT infrastructure	SPS003, SPS083, SPS092, SPS137, SPS143, SPS145, SPS176, SPS187	SPS020, SPS027, SPS029, SPS126, SPS173, SPS223	SPS032, SPS033, SPS054, SPS140, SPS197, SPS215
	HPC	SPS083	SPS027	
	Security	SPS064, SPS083, SPS092, SPS157, SPS192	SPS126, SPS165	

RQ	Topics	2022	2023	2024
	Cloud computing	SPS003, SPS137, SPS143	SPS029, SPS126, SPS173	SPS032, SPS033, SPS197

Table 16. Studies with the Highest IRRQ Index, Classified by Topic

RQ	Topics	2022	2023	2024
Q1	Research	SPS002, SPS003, SPS007, SPS039, SPS044, SPS053, SPS059, SPS064, SPS070, SPS071, SPS073, SPS080, SPS083, SPS092, SPS137, SPS143, SPS145, SPS146, SPS155, SPS157, SPS176, SPS177, SPS187, SPS192	SPS027, SPS029, SPS055, SPS066, SPS067, SPS068, SPS081, SPS093, SPS094, SPS117, SPS126, SPS134, SPS153, SPS165, SPS167, SPS173, SPS174, SPS183, SPS195, SPS205, SPS209, SPS221, SPS223, SPS226	SPS005, SPS008, SPS010, SPS019, SPS021, SPS028, SPS030, SPS032, SPS033, SPS036, SPS045, SPS048, SPS054, SPS061, SPS082, SPS106, SPS107, SPS113, SPS129, SPS136, SPS140, SPS151, SPS168, SPS172, SPS178, SPS184, SPS197, SPS198, SPS214, SPS215, SPS216, SPS219
	Education	SPS038, SPS058, SPS101, SPS146, SPS187, SPS204	SPS020, SPS072, SPS116, SPS120, SPS152, SPS206, SPS207, SPS218	SPS089, SPS096, SPS115, SPS151, SPS163, SPS198, SPS199
	Outreach	SPS002, SPS031, SPS037	SPS078, SPS112	SPS010, SPS063, SPS114
Q2	Software development	SPS002, SPS037, SPS038, SPS044, SPS053, SPS058, SPS101	SPS078, SPS120, SPS183, SPS195	SPS008, SPS010, SPS028, SPS096, SPS172, SPS215
	Computational thinking	SPS187	SPS116	SPS115, SPS198
	Parallel computing		SPS020, SPS134, SPS223	
	Data analysis	SPS037, SPS071, SPS157	SPS183, SPS209	SPS005, SPS028, SPS045, SPS061, SPS082, SPS129
	Artificial Intelligence	SPS073	SPS209	SPS082
	Computer networks	SPS187	SPS094	SPS010, SPS019, SPS048, SPS106, SPS113, SPS198, SPS216, SPS219
	IT infrastructure	SPS003, SPS007, SPS031, SPS037, SPS038, SPS039, SPS070, SPS073, SPS083, SPS092, SPS137, SPS143, SPS145, SPS146, SPS155, SPS176, SPS177, SPS187, SPS204	SPS020, SPS027, SPS029, SPS055, SPS066, SPS067, SPS068, SPS078, SPS081, SPS094, SPS112, SPS117, SPS126, SPS134, SPS152, SPS167, SPS173, SPS174, SPS183, SPS205, SPS206, SPS207, SPS218, SPS223	SPS019, SPS021, SPS030, SPS032, SPS033, SPS036, SPS048, SPS054, SPS082, SPS089, SPS096, SPS106, SPS107, SPS115, SPS129, SPS136, SPS140, SPS151, SPS163, SPS168, SPS172, SPS178, SPS184, SPS197, SPS198, SPS199, SPS214, SPS215, SPS216, SPS219
	HPC	SPS083	SPS027, SPS134	SPS008, SPS114, SPS129, SPS178
	Security	SPS064, SPS070, SPS083, SPS092, SPS155, SPS157, SPS192	SPS081, SPS093, SPS094, SPS126, SPS153, SPS165, SPS183, SPS221, SPS226	SPS082, SPS129, SPS214, SPS219
	Cloud computing	SPS002, SPS003, SPS031, SPS070, SPS071, SPS080, SPS137, SPS143, SPS146, SPS177	SPS029, SPS055, SPS126, SPS173	SPS019, SPS030, SPS032, SPS033, SPS045, SPS136, SPS163, SPS197, SPS214, SPS216

Table 17. Classification of SPS studies by technology of **VBC** and academic dimension

Topics	Education	Research	Outreach
CRI-O		SPS068, SPS083	
Containerd		SPS066, SPS068, SPS083, SPS223	
Docker	SPS020, SPS038, SPS042, SPS058, SPS072, SPS089, SPS096, SPS101, SPS115, SPS116, SPS120, SPS124, SPS152, SPS187, SPS198, SPS199, SPS204, SPS206, SPS207, SPS218	SPS002, SPS004, SPS005, SPS007, SPS008, SPS011, SPS017, SPS021, SPS030, SPS039, SPS040, SPS041, SPS043, SPS044, SPS045, SPS046, SPS048, SPS049, SPS051, SPS053, SPS054, SPS055, SPS059, SPS060, SPS061, SPS065, SPS066, SPS071, SPS074, SPS079, SPS080, SPS081, SPS083, SPS093, SPS097, SPS099, SPS100, SPS102, SPS103, SPS104, SPS105, SPS106, SPS107, SPS119, SPS122, SPS124, SPS126, SPS129, SPS133, SPS153, SPS155, SPS172, SPS173, SPS174, SPS176, SPS177, SPS180, SPS182, SPS187, SPS188, SPS191, SPS192, SPS197, SPS198, SPS205, SPS209, SPS216, SPS219, SPS220, SPS221, SPS225, SPS226	SPS002, SPS037, SPS063, SPS078, SPS099, SPS112, SPS114, SPS220
Firecracker		SPS107, SPS205	
Google gVisor		SPS107, SPS184, SPS205	
Hyper-V containers		SPS068	
Kata Containers		SPS184, SPS205, SPS224	
LXC		SPS066, SPS068, SPS083, SPS157	
LXD		SPS068, SPS083	
OpenVZ		SPS083	
Podman		SPS007, SPS046, SPS060, SPS068, SPS083, SPS129, SPS174	
Rkt		SPS068, SPS083	
Singularity		SPS041, SPS060, SPS068	
Udocker		SPS027, SPS068	

Table 18. Classification of SPS studies by IT domain and academic dimension

Topics	Education	Research	Outreach
Data analysis		SPS001, SPS005, SPS028, SPS045, SPS061, SPS071, SPS082, SPS129, SPS157, SPS183, SPS209	SPS037
Blockchain			SPS063
Cloud computing	SPS146, SPS163	SPS002, SPS003, SPS012, SPS015, SPS018, SPS019, SPS025, SPS026, SPS029, SPS030, SPS032, SPS033, SPS043, SPS045, SPS055, SPS056, SPS069, SPS070, SPS071, SPS079, SPS080, SPS084, SPS085, SPS087, SPS091, SPS099, SPS109, SPS111, SPS126, SPS136, SPS137, SPS143, SPS146, SPS149, SPS173, SPS177, SPS179, SPS185, SPS193, SPS194, SPS197, SPS202, SPS210, SPS213, SPS214, SPS216, SPS217, SPS222	SPS002, SPS031, SPS099, SPS213
Parallel computing	SPS020	SPS017, SPS134, SPS223	
Software development	SPS038, SPS042, SPS058, SPS096, SPS101, SPS120	SPS002, SPS008, SPS010, SPS015, SPS022, SPS028, SPS043, SPS044, SPS053, SPS086, SPS098, SPS100, SPS118, SPS133, SPS172, SPS183, SPS195, SPS215, SPS224	SPS002, SPS010, SPS037, SPS078
HPC		SPS008, SPS014, SPS017, SPS018, SPS027, SPS041, SPS062, SPS083, SPS090, SPS098, SPS121, SPS129, SPS134, SPS178, SPS194, SPS200	SPS114
Artificial intelligence	SPS072	SPS011, SPS023, SPS027, SPS030, SPS040, SPS051, SPS053, SPS059, SPS073, SPS077, SPS080, SPS082, SPS095, SPS142, SPS148, SPS149, SPS154, SPS161, SPS169, SPS170, SPS177, SPS183, SPS209	SPS037, SPS078, SPS181
Computational thinking	SPS042, SPS115, SPS116, SPS187, SPS198	SPS187, SPS198	
Computer networks	SPS139, SPS187, SPS198	SPS010, SPS019, SPS046, SPS048, SPS094, SPS103, SPS105, SPS106, SPS110, SPS113, SPS132, SPS159, SPS164, SPS187, SPS198, SPS216, SPS219	SPS010

Topics	Education	Research	Outreach
Security		SPS010, SPS019, SPS046, SPS048, SPS094, SPS103, SPS105, SPS106, SPS110, SPS113, SPS132, SPS159, SPS164, SPS187, SPS198, SPS216, SPS219	
IT infrastructure	SPS020, SPS038, SPS075, SPS089, SPS096, SPS115, SPS124, SPS146, SPS151, SPS152, SPS163, SPS187, SPS198, SPS199, SPS204, SPS206, SPS207, SPS218	SPS003, SPS004, SPS007, SPS009, SPS011, SPS012, SPS014, SPS017, SPS018, SPS019, SPS021, SPS023, SPS024, SPS025, SPS026, SPS027, SPS029, SPS030, SPS032, SPS033, SPS034, SPS036, SPS039, SPS046, SPS047, SPS048, SPS049, SPS051, SPS052, SPS054, SPS055, SPS056, SPS057, SPS060, SPS062, SPS066, SPS067, SPS068, SPS069, SPS070, SPS073, SPS074, SPS075, SPS076, SPS077, SPS079, SPS081, SPS082, SPS083, SPS084, SPS085, SPS087, SPS088, SPS090, SPS091, SPS092, SPS094, SPS095, SPS099, SPS100, SPS102, SPS103, SPS104, SPS105, SPS106, SPS107, SPS109, SPS110, SPS111, SPS117, SPS119, SPS121, SPS122, SPS123, SPS124, SPS125, SPS126, SPS129, SPS130, SPS131, SPS132, SPS134, SPS135, SPS136, SPS137, SPS140, SPS143, SPS144, SPS145, SPS146, SPS148, SPS149, SPS150 SPS151, SPS154, SPS155, SPS156, SPS159, SPS160, SPS164, SPS167, SPS168, SPS169, SPS170, SPS171, SPS172, SPS173, SPS174, SPS175, SPS176, SPS177, SPS178, SPS179, SPS180, SPS182, SPS183, SPS184, SPS185, SPS186, SPS187, SPS188, SPS189, SPS190, SPS196, SPS197, SPS198, SPS200, SPS201, SPS205, SPS208, SPS210, SPS212, SPS213, SPS214, SPS215, SPS216, SPS217, SPS219, SPS220, SPS222, SPS223, SPS224, SPS225	SPS031, SPS037, SPS078, SPS099, SPS112, SPS181, SPS208, SPS211, SPS213, SPS220

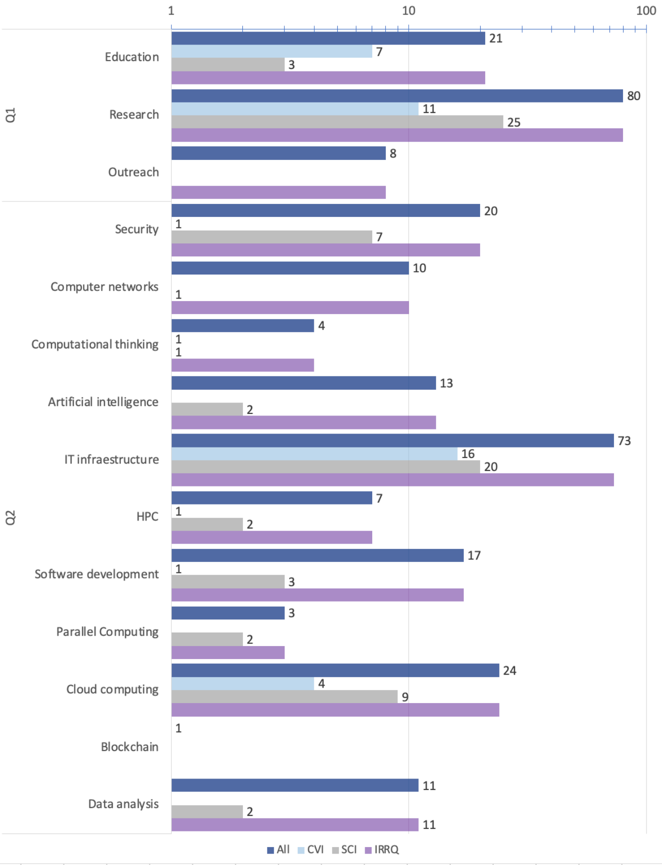

Figure 12. SPS by quality indices, topics, and research questions

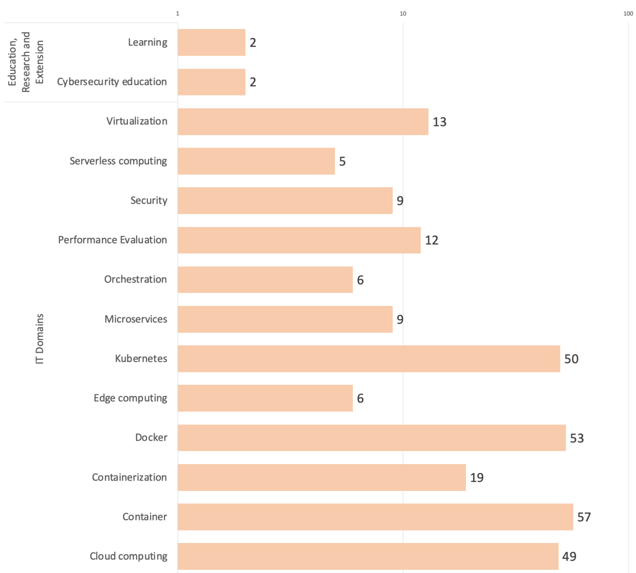

Figure 13. SPS keyword co-occurrence analysis

4.6.2 Word Cloud Visualization

Figure 14 presents the keyword cloud generated from the 226 SPS (terms with frequency > 1). The three dominant clusters—*Docker*, *Container*, *Kubernetes*, *Cloud Computing* (61.6%); *Containerization*, *Container Orchestration*, *Virtualization*, *Microservices* (13.08%); and *Performance evaluation*, *Edge computing*, *Machine learning*, *Security* (9.09%)—reflect the current thematic structure of CBV research. Notably, terms related to education, teaching, and outreach are absent from the high-frequency clusters, confirming the finding that academic applications of CBV remain an under-investigated research area.

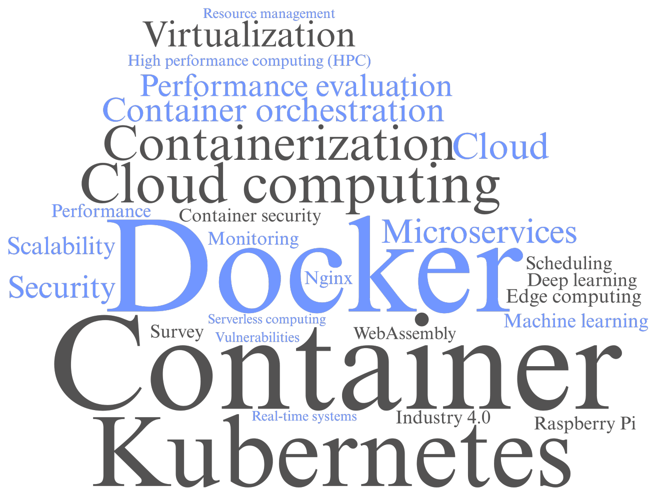

Figure 14. Keyword cloud of the 226 SPS

4.6.3 *Reproducibility*

To ensure full reproducibility, two verification mechanisms are provided:

1) A public SMS-Builder instance containing all process data: https://sms-vbc.iti.grid.uniquindio.edu.co/sms.xhtml. Credentials: *"invitado"* for both username and password.
2) A Docker image integrating all required documentation: https://hub.docker.com/r/anubis1001/tg-vbc-sms-builder.

5 Threats to Validity

Four categories of threats to validity are identified, along with the mitigation strategies employed.

5.1 Selection Bias

Seven measures were implemented to mitigate selection bias. First, the SMS followed established guidelines Runeson and Höst [2009]; Kitchenham et al. [2010], including GQM and PICOC frameworks. Second, five major databases were queried. Third, synonyms were included for all key terms to ensure broad coverage. Fourth, search strings were iteratively refined through pilot searches. Fifth, a hybrid strategy combining database search with snowballing increased coverage. Sixth, alert systems (Endnote, Mendeley, Google Scholar) monitored for newly published studies. Seventh, three quality indices (CVI, SCI, IRRQ) provided complementary assessment perspectives. The CVI and IRRQ indices carry inherent subjectivity; this was mitigated through collaborative evaluation by an odd number of independent evaluators ($K \geq 3$).

5.2 Classification Errors

Studies were classified according to the topics defined during planning, corresponding to CBV technologies, IT domains, education, research, and outreach. Multi-topic classification was permitted when a study's scope spanned multiple areas. All classifications underwent peer review by an odd number of evaluators to reduce individual bias.

5.3 Data Extraction Inaccuracy

The SMS-Builder software Candela-Uribe et al. [2020] was used for structured data extraction, minimizing manual processing errors. Peer review was conducted on extracted data following the recommendations of Kitchenham and Charters Kitchenham et al. [2010].

5.4 Search Protocol Errors

The search protocol was executed under peer review: one evaluator implemented the protocol while a second independently verified the process. SMS-Builder was used throughout to reduce manual data handling and ensure process consistency.

6 Analysis, Discussion, and Future Research Directions

The SMS results reveal several cross-cutting patterns that merit interpretation beyond descriptive statistics. This section synthesizes the key findings, proposes a taxonomic structure, identifies research gaps, and outlines concrete future research directions.

6.1 Proposed Taxonomic Structure

The classification of 226 SPS across IT domains and academic dimensions motivates a taxonomic structure (Figure 15) that organizes the CBV research landscape along two axes: *(i)* the IT domain (software development, IT infrastructure, cloud computing, HPC, security, AI, etc.) and *(ii)* the academic dimension (education, research, outreach). This dual-axis taxonomy constitutes a novel contribution, as no prior secondary study has simultaneously mapped both dimensions. The taxonomy can serve as a decision-support tool for researchers identifying relevant literature, for educators designing container-based curricula, and for practitioners selecting technologies aligned with domain-specific requirements.

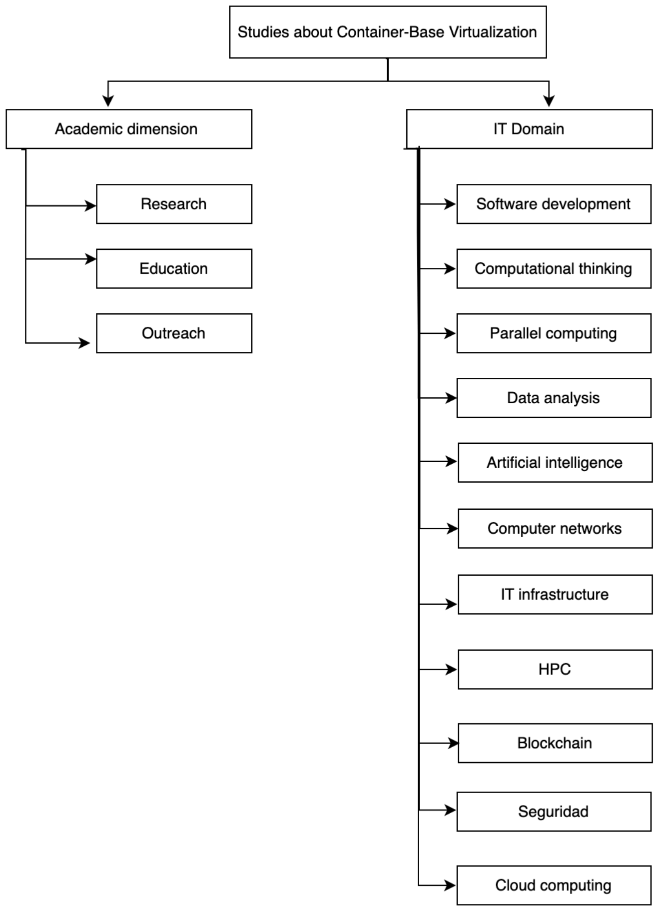

Figure 15. Proposed taxonomic structure for CBV research

6.2 Key Findings and Interpretation

Technology concentration and its implications. The dominance of Docker (94 SPS, 41.6%) and Kubernetes (67 SPS) reveals a significant concentration risk in the research literature. While Docker's ubiquity reflects its first-mover advantage and ecosystem maturity, it also implies that findings from the CBV research corpus may not generalize to alternative runtimes with different security models (gVisor, Kata Containers), permission models (Podman), or HPC optimization (Singularity/Apptainer). Researchers should critically evaluate whether conclusions drawn from Docker-centric studies apply to their specific deployment contexts.

The IT Infrastructure bias. IT Infrastructure accounts for 75.66% of the mapped studies, creating a pronounced bias toward deployment and management concerns. Domains such as Blockchain (0.76%), Parallel Computing (1.77%), and Computational Thinking (2.21%) remain severely underexplored despite clear potential for containerization. For instance, container-based approaches to reproducible blockchain testing environments, portable parallel computing frameworks, and interactive computational thinking platforms represent viable but unaddressed research directions.

The academic dimension gap. The fragmentation across academic dimensions—with Research dominating (83.61%) and Outreach representing only 5.88%—reveals a missed opportunity. Containerization's core strengths (portability, reproducibility, environment isolation) are precisely the attributes needed for effective outreach and knowledge transfer. The absence of studies simultaneously addressing education, research, and outreach suggests that the academic community has not yet leveraged CBV's transversal potential.

Temporal trends and maturation signals. The 118% growth in publications from 2022 to 2024, combined with the increasing CVI and IRRQ indices, indicates both growing interest and improving methodological alignment with the field's core questions. However, the stable SCI around 18 suggests that while more studies are published, citation impact has not proportionally increased—a pattern consistent with a rapidly expanding but potentially fragmenting research area.

6.3 Identified Research Gaps

Based on the SMS findings, the following research gaps are identified:

RG1: **Alternative runtime evaluation.** Systematic comparative studies of container runtimes beyond Docker (e.g., Podman, Singularity, gVisor, Kata Containers) across performance, security, and usability dimensions are critically needed.

RG2: **Orchestration beyond Kubernetes.** Research evaluating lightweight orchestration alternatives (K3s, Nomad, Docker Compose) for edge computing, IoT, and resource-constrained environments is underrepresented.

RG3: **CBV in education and outreach.** Empirical studies measuring the impact of containerization on learning outcomes, curriculum design, and outreach program effectiveness are nearly absent from the literature.

RG4: **Cross-domain integration.** No identified study bridges all three academic dimensions simultaneously, presenting an opportunity for holistic CBV adoption frameworks.

RG5: **Emerging IT domains.** The intersection of CBV with blockchain, quantum computing simulation, and computational thinking requires dedicated investigation.

RG6: **Security of container ecosystems.** While security appears in 65 SPS, most address container isolation rather than supply-chain security, image provenance, or runtime attestation—areas of growing practical concern.

6.4 Future Research Directions

Building on the identified gaps, the following concrete research directions are proposed:

- **Benchmarking frameworks:** Development of standardized benchmarking methodologies for comparing container runtimes and orchestrators across heterogeneous hardware (x86, ARM, RISC-V) and workload profiles (HPC, microservices, AI training).
- **Educational impact studies:** Controlled experiments measuring the effect of container-based laboratory environments on student learning outcomes, engagement, and skill transferability in computer science education.
- **Outreach and knowledge transfer:** Design and evaluation of container-packaged educational platforms that facilitate technology transfer from universities to industry and communities, particularly in resource-limited settings.
- **Security posture analysis:** Comprehensive studies on container supply-chain security, including image scanning effectiveness, Software Bill of Materials (SBOM) adoption, and runtime security monitoring in production environments.
- **Lightweight orchestration for edge/IoT:** Empirical evaluation of Kubernetes alternatives in edge and IoT deployments where resource constraints and latency requirements differ from cloud-native assumptions.

6.5 Implications for Research and Practice

For *researchers*, this SMS provides a structured entry point into the CBV literature, enabling targeted investigation of underexplored domains and informed positioning of new contributions. The identified gaps (RG1–RG6) offer concrete starting points for future studies. For *practitioners*, the technology distribution analysis highlights both the safety of Docker/Kubernetes adoption (given extensive research backing) and the risk of overlooking better-suited alternatives for specific use cases. For *educators*, the near-absence of containerization in formal educational frameworks represents an opportunity to develop innovative pedagogical approaches leveraging CBV's reproducibility and portability.

7 Conclusions

This paper presented a Systematic Mapping Study (SMS) on container-based virtualization (CBV) technologies, covering 226 primary studies published between 2022 and 2024. The study employed a hybrid search strategy (database queries and snowballing), three quality assessment indices (CVI, SCI, IRRQ), and a dual-axis classification spanning 11 IT domains and three academic dimensions (education, research, outreach).

The main contributions and findings are as follows:

1. **Comprehensive mapping:** The SMS provides the first systematic mapping that simultaneously covers CBV technologies across IT domains and academic dimensions, addressing a gap identified in all prior secondary studies.
2. **Technology concentration:** Docker (41.6%) and Kubernetes (29.6%) dominate the research landscape, while alternative runtimes (Podman, Singularity, gVisor) and orchestrators (K3s, Nomad) remain significantly underrepresented despite their growing industrial relevance.
3. **Domain imbalance:** IT Infrastructure accounts for 75.66% of the corpus, while domains such as Blockchain (0.76%), Parallel Computing (1.77%), and Computational Thinking (2.21%) represent critical blind spots in current research.
4. **Academic fragmentation:** Research dominates (83.61%) while Education (11.06%) and Outreach (5.88%) remain underexplored. No study simultaneously addresses all three academic dimensions, indicating that CBV's transversal potential for academic activities remains unrealized.
5. **Taxonomic structure:** A novel dual-axis taxonomy organizes the CBV literature by IT domain and academic dimension, providing a structured reference for researchers, educators, and practitioners.

6. **Research gaps:** Six concrete gaps (RG1–RG6) were identified, with corresponding future research directions including alternative runtime benchmarking, educational impact studies, outreach frameworks, supply-chain security analysis, and lightweight orchestration for edge/IoT.

The growing publication rate (118% increase from 2022 to 2024) confirms the vitality of this research area but also underscores the risk of literature saturation without adequate systematization. The taxonomic structure and reproducibility artifacts provided with this study aim to mitigate this challenge.

As future work, we plan to conduct controlled comparative evaluations of container runtimes and orchestrators across heterogeneous hardware platforms, and to design and evaluate container-based pedagogical frameworks for computer science education.

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