



Object-Oriented Design Principles in Microservices and Cloud-Based Software Architecture: A Scoping Review

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ABSTRACT

The evolution of software architecture from monolithic systems to microservices and cloud-native deployments has reignited debates regarding the relevance of Object-Oriented Programming (OOP) design principles in distributed environments. This scoping discussion synthesizes empirical evidence from 47 peer-reviewed studies published between 2020 and 2026 to evaluate how core OOP principles - encapsulation, inheritance, polymorphism, abstraction, and SOLID guidelines - translate to microservices and cloud-based architectures. We assessed 156 full-text articles, and included 47 studies meeting quality criteria. Findings indicate that OOP principles remain highly relevant for microservices design, particularly SOLID's Single Responsibility Principle (aligned with bounded contexts), Dependency Inversion (enabling loose coupling), and Interface Segregation (supporting API design). However, challenges emerge in distributed settings, including network-induced latency, service granularity trade-offs, and the tension between object encapsulation and cross-service data consistency. We identify five key patterns where OOP principles successfully integrate with microservices: Domain-Driven Design aggregates, Repository pattern for data access, Factory pattern for service instantiation, Strategy pattern for polymorphic behavior, and CQRS for separation of concerns. The review reveals significant gaps in empirical validation, with only 12% and 23% of studies including quantitative and qualitative performance metrics. We conclude that OOP principles provide valuable conceptual foundations for microservices architecture but require reinterpretation at system boundaries rather than direct application. Future research should prioritize empirical studies comparing OOP-based versus functional or procedural microservices implementations across scalability, maintainability, and operational efficiency dimensions.

CITATION

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INTRODUCTION

The transition from monolithic to microservices architecture represents one of the most significant paradigm shifts in software engineering over the past decade. Microservices -small, independently deployable services communicating via lightweight protocols - promise improved scalability, maintainability, and organizational agility compared to traditional monolithic systems. Concurrently, cloud computing has matured as the dominant deployment platform, offering elastic infrastructure, managed services, and container orchestration through Kubernetes and serverless platforms (Rodrigues et al., 2014).

Amid this architectural evolution, Object-Oriented Programming (OOP) - the dominant paradigm for enterprise software development since the 1990s faces renewed scrutiny. OOP's core principles (encapsulation, inheritance, polymorphism, abstraction) and refinements such as SOLID (Single Responsibility, Open-Closed, Liskov Substitution, Interface Segregation, Dependency Inversion) were conceived for single-process, shared-memory environments. Their applicability to distributed, network-bound microservices architectures remains contested, with some researchers advocating functional programming's immutability and pure functions as better suited for concurrent, distributed systems (Learn.microsoft, 2026).

Object-Oriented Design Principles

Object-Oriented Programming emerged with Simula in the 1960s and gained widespread adoption through languages such as C++, Java, C#, and Python. OOP's four pillars provide mechanisms for managing complexity in large-scale software systems (Khan et al., 2025). Encapsulation bundles data and behavior within objects, restricting direct access to internals and exposing controlled interfaces, thereby supporting modularity and information hiding (Hasan, 2026). Inheritance enables hierarchical classification and code reuse through parent-child relationships, promoting polymorphism and extensibility. Polymorphism allows objects to be treated uniformly through shared interfaces, enabling interchangeable implementations and improving flexibility and testability. Abstraction hides implementation complexity behind simplified interfaces, reducing cognitive load with abstract classes and interfaces defining contracts that concrete implementations must satisfy (Khan et al., 2025).

The SOLID principles refine OOP design for improved modularity and maintainability (Learn.microsoft, 2026). The Single Responsibility Principle (SRP) states that a class should have only one reason to change, limiting complexity and easing security auditing and testing (IONOS editorial team, 2025). The Open-Closed Principle (OCP) requires classes to be open for extension but closed for modification, supporting the addition of new features

without altering existing code (Jamie, 2025). The Liskov Substitution Principle (LSP) mandates that derived classes be substitutable for their base classes without altering correctness, preserving behavioral guarantees across inheritance hierarchies (IONOS editorial team, 2025). The Interface Segregation Principle (ISP) advises that clients should not depend on interfaces they do not use, reducing coupling and exposure of unused methods (Raphael & Marcos, 2024). The Dependency Inversion Principle (DIP) states that high-level modules should depend on abstractions rather than concrete implementations, enabling flexible composition and testing through dependency injection (IONOS editorial team, 2025).

Microservices and Cloud-Native Architecture

Microservices architecture decomposes applications into small, autonomous services interacting via APIs (Erik, 2025). Key characteristics include independent deployment, loose coupling through well-defined interfaces, bounded contexts that encapsulate cohesive business domains, decentralized data management with service-owned data stores, and fault isolation so that failures in one service do not cascade to others. These properties can improve scalability, maintainability, and organizational agility, but also introduce challenges such as inter-service communication complexity, distributed data consistency, and operational overhead (Rodrigues et al., 2014).

Cloud-native architecture leverages cloud computing capabilities such as containers, orchestration, serverless, and managed services to build scalable and resilient applications (Madrigan, 2025). Containerization (e.g., Docker) packages applications with their dependencies for consistent deployment. Orchestration platforms such as Kubernetes automate deployment, scaling, and management of containerized workloads. Serverless computing (e.g., AWS Lambda, Azure Functions) eliminates server management and enables automatic scaling. Service meshes (e.g., Istio, Linkerd) handle service-to-service communication, security, and observability (Preetham, 2025), while API gateways (e.g., Kong, AWS API Gateway) provide centralized entry points for routing, authentication, and rate limiting (Madrigan, 2025). Although cloud-native principles operate primarily at the infrastructure level, they align conceptually with OOP's emphasis on modularity and encapsulation (Vineet, 2026).

Integrating OOP with Microservices

Integrating OOP with microservices requires reinterpreting object-level principles at service boundaries. Recent work suggests that OOP's emphasis on encapsulation and loose coupling maps naturally to microservices' bounded contexts and API-driven communication. Encapsulated domain objects and well-defined interfaces can support

clear service boundaries, while SOLID principles can guide the internal design of individual services. However, challenges arise in distributed environments, including network latency, eventual consistency, and the tension between object encapsulation and cross-service data access (Dinda et al., 2026). These tensions motivate a scoping discussion examination of how OOP principles are actually applied, adapted, or contested in microservices and cloud-native contexts.

Research Gap and Objectives

Recent comparative studies suggest that OOP remains relevant for microservices, offering balanced abstraction and modularity beneficial for service-based design. However, empirical synthesis is fragmented across disparate studies, with no comprehensive scoping review evaluating OOP principles' effectiveness in microservices and cloud-native contexts. This gap impedes evidence-based decision-making for practitioners and researchers navigating architectural choices (Khan et al., 2025). This scoping review addresses three research questions (RQ): RQ1: How are core OOP principles (encapsulation, inheritance, polymorphism, abstraction, SOLID) applied in microservices and cloud-based architectures?

RQ2: What benefits and challenges arise from applying OOP design principles to microservices architecture?

RQ3: What design patterns successfully integrate OOP principles with microservices and cloud-native deployment?

Our contributions include Scoping Synthesis: The comprehensive scoping review of OOP principles in microservices architecture. Evidence-Based Framework: Identification of five design patterns namely Domain-Driven Design (DDD) aggregates, Repository, Factory, Strategy, and CQRS that successfully integrate OOP with microservices. Research Gaps: Documentation of significant empirical gaps, with only 12% of studies including quantitative validation, highlighting opportunities for future research. Practical Guidance: Reinterpretation of SOLID principles for distributed systems, aligning with recent industry practices in cloud-native architecture.

This scoping review aims to synthesize published evidence on the application of object-oriented design principles in microservices and cloud-based software architecture, identify reported benefits and challenges, and examine the design patterns used to adapt these principles to distributed systems.

REVIEW METHODOLOGY

This scoping review ensure methodological rigor and reproducibility (Rodrigues et al., 2014).

We searched five digital libraries and databases: IEEE Xplore, ACM Digital Library, Scopus, Web of Science, and Google Scholar. Our search terms combined the following

OOP and microservices concepts: (a) "object-oriented" OR OOP OR SOLID OR "design patterns" (b) "microservices" OR "micro-services" OR "cloud-native" OR "cloud native", and (c) "architecture" OR "design" OR "principles". Searches were limited to peer-reviewed articles published in English between 2014 and 2026.

Study Selection

Selection followed a three-stage process: (1) Screening: Titles and abstracts were screened for relevance to OOP principles in microservices/cloud architecture. (2) Eligibility: Full texts were assessed against inclusion/exclusion criteria. (3) Inclusion: Studies were included if they discussed OOP design principles applied to microservices or cloud-native architecture and provided empirical evidence or detailed case studies.

Inclusion Criteria involves: Peer-reviewed conference or journal articles, Published between 2014–2026, Focus on OOP principles (encapsulation, inheritance, polymorphism, SOLID, design patterns), Applied to microservices or cloud-based architecture, and English language

Two reviewers independently screened titles and abstracts and independently assessed potentially eligible full texts. Disagreements were resolved through discussion; where consensus was not reached, a third reviewer adjudicated.

Data Extraction and Synthesis

Data extracted included studies from: (a) Publication details (year, venue, authors), (b) Research type (empirical, case study, theoretical, scoping review), (c) OOP principles discussed, (d) Microservices/cloud context, (e) Benefits and challenges reported, (f) Design patterns identified, (g) Quantitative metrics (if any)

Studies were synthesized qualitatively due to heterogeneity in research designs and metrics. Narrative synthesis identified common themes, patterns, and gaps across studies. Studies were also assessed for quality using a checklist adapted from software engineering scoping reviews: Clear research questions or objectives, appropriate methodology for research type, transparent data collection and analysis, discussion of limitations and reproducibility of findings.

Studies scoring below 2/3 on quality criteria were excluded from synthesis because (1) they did not examine OOP principles in relation to microservices or cloud-based architecture (2) they were Published outside the eligible date range or in a language other than English and (3) they did not provide sufficient evidence or detail for inclusion

RESULTS

After title/abstract screening, 156 full-text articles were assessed for eligibility. Of these, 47 studies met inclusion criteria and quality thresholds.

Study Characteristics

The characteristics of the included studies comprising of 47 peer-reviewed publications are summarized in Tables 1 and 3.

Table 1: Publication Year (N = 47)

Publication Year	Count	Percentage
2020	3	6%
2021	5	11%
2022	7	15%
2023	9	19%
2024	12	26%
2025	9	19%
2026	2	4%

Table 2: Research Types (N = 47 each)

Research Year	Count	Percentage
Empirical (quantitative)	6	12%
Empirical (qualitative)	11	23%
Case Study	15	32%
Theoretical/Conceptual	10	21%
Scoping Review	5	11%

Table 3: Research Venue (N = 47 each)

Venue Type	Count	Percentage
Journal	28	60%
Conference	19	40%

Research questions’ examinations and synthesis

This section presents the findings of the scoping review organized by research question. RQ1 examines how core OOP principles and design patterns are applied in microservices and cloud-based architectures. RQ2 synthesizes reported benefits and challenges of applying OOP design principles to microservices. To enhance

clarity and conciseness, results are summarized in tabular form

RQ1: Application of OOP Principles in Microservices
Tables 4 to 7 summarizes how each OOP principle and key design patterns are applied in microservices contexts, including frequency of discussion across the 47 included studies, main applications, and reported challenges

Table 4: Encapsulation - Studies Mentioning (n = 47); Mentioned (38 = 81%)

Main Applications in Microservices	Reported Challenges
- Service boundaries align with object encapsulation; each service encapsulates a bounded context and exposes APIs as controlled interfaces (Hasan, 2026). - Microservices viewed as “large-grained objects” encapsulating data and behavior, APIs analogous to public methods (Khan et al., 2025). - Data hiding at service level enforces data sovereignty and reduces coupling (Dinda et al., 2026). - API contracts (OpenAPI, gRPC) serve as interfaces, enabling polymorphic implementations and versioning (Preetham, 2025).	- Network boundaries introduce latency compared to in-process method calls (Rodrigues et al., 2014). - Encapsulation complicates queries requiring data from multiple services, necessitating patterns such as API Composition or CQRS (Chenxing et al., 2025).

Table 5: SOLID Principles - Studies Mentioning (n = 47); Mentioned (32 = 68%)

Main Applications in Microservices	Reported Challenges
- SRP: Aligns with bounded contexts; services encapsulate cohesive business capabilities (IONOS editorial team, 2025). Service-level SRP emphasizes business capability ownership rather than overly fine-grained technical responsibilities. - OCP: Supports API versioning and backward compatibility; stable API contracts and event schemas reduce breaking changes. Services extended via API composition, event-driven workflows, or sidecar patterns without modifying core logic (Preetham, 2025). - LSP: Substitutability interpreted as stable API responses and event payloads that do not break consumers; requires careful API versioning. - ISP: Lean API surfaces designed around specific client needs, avoiding over-fetching and large generic contracts (Raphael & Marcos, 2024). - DIP: Abstractions and dependency injection decouple services from infrastructure (databases, message brokers, external APIs); aligns with event-driven decoupling and asynchronous messaging (Abhishek, 2026).	- SRP: Excessive adherence can lead to over-fragmented services, increasing operational complexity and network calls (Dinda et al., 2026). - LSP: Distributed substitutability complicated by network failures, latency variations, and partial outages (Hasan, 2026). - OCP/LSP: Versioning and backward compatibility require disciplined API and schema management.

Table 6: Inheritance - Studies Mentioning (n = 47); Mentioned (19 = 40%), Polymorphism (Discussed within design patterns and API design; no separate count reported)

Main Applications in Microservices	Reported Challenges
Inheritance: - Code reuse within services via base classes and shared libraries (Sadhana, 2023). - Service templates with common functionality (logging, authentication) extended by specific services, analogous to inheritance (Hasan, 2026). Polymorphism: - API polymorphism: different service implementations satisfy the same API contract, enabling polymorphic behavior at runtime (e.g., A/B testing, regional variations). - Realized through design patterns (Strategy, Factory) that enable interchangeable implementations within services (Hasan, 2026).	- Inheritance across services is problematic due to network boundaries and deployment independence. - Shared libraries can cause tight coupling and anti-patterns in distributed systems (Dinda et al., 2026). - Requires robust API versioning and contract management to avoid breaking consumers when implementations change.

Table 7: Design Patterns - Studies Mentioning (n = 47); Mentioned (35 = 74%)

Main Applications in Microservices	Reported Challenges
- DDD Aggregates (18/35): Bounded contexts and aggregates align with service boundaries, encapsulating domain logic and data (Chenxing et al., 2025). - Repository (22/35): Abstracts data access, enabling caching, sharding, and distributed data stores. - Factory (14/35): Encapsulates service/client instantiation, enabling centralized configuration, dependency injection, and secure communication setup (Hasan, 2026). - Strategy (12/35): Enables polymorphic behavior within services (e.g., different pricing algorithms, authentication methods) (Sadhana, 2023). - CQRS (16/35): Separates read and write operations, enabling independent scaling and optimization of query and command paths (Chenxing et al., 2025).	- Patterns introduce additional architectural complexity and require expertise to apply correctly. - CQRS and event-driven patterns increase operational and debugging complexity in distributed environments.

In Tables 4 through 7, percentages were calculated with respect to the total number of included studies ($n = 47$). For design patterns, counts are relative to the 35 studies that discussed patterns. Overall, encapsulation and design patterns were the most frequently discussed OOP-related concepts, appearing in 81% and 74% of studies, respectively. SOLID principles were also prominent (68%), whereas inheritance was less emphasized at the service

level (40%), reflecting its primary relevance within individual services rather than across service boundaries.

RQ2: Benefits

Tables 8 and 9 summarize the benefits and challenges reported across the 47 included studies when applying OOP principles to microservices architectures.

Table 8: Benefits - Studies Mentioning ($n = 47$); Mentioned ($41 = 87\%$)

Specific Aspect	Frequency (out of 41 studies reporting benefits)	Summary of Findings
Improved Modularity	31/41	OOP's emphasis on encapsulation and loose coupling aligns with microservices' modular architecture, improving maintainability and understandability (Hasan, 2026).
Enhanced Testability	28/41	Interface-based design and dependency injection enable test isolation through mocking and stubbing, supporting unit and integration testing.
Code Reuse	22/41	Inheritance and composition mechanisms enable code reuse within services through base classes, shared libraries, and utility modules (Khan et al., 2025).
Clear Abstractions	26/41	Abstraction mechanisms (interfaces, abstract classes) provide clear contracts for service APIs, improving documentation and reducing integration errors.
Organizational Alignment	19/41	OOP's bounded contexts (via DDD) align with team structures, enabling autonomous development and deployment (Chenxing et al., 2025).

Challenges

Table 9: Challenges - Studies Mentioning ($n = 47$); Mentioned ($39 = 83\%$)

Specific Aspect	Frequency (out of 39 studies reporting challenges)	Summary of Findings
Network Latency	27/39	Network-induced latency contrasting with OOP's assumption of in-process method calls (Rodrigues et al., 2014).
Distributed Data Consistency	24/39	OOP's encapsulation complicates cross-service queries and transactions, requiring eventual consistency and complex patterns (Saga, CQRS) (Chenxing, et al., 2025).
Service Granularity	21/39	Difficulty in determining appropriate service boundaries, with excessive adherence to SRP leading to over-fragmentation and operational overhead (Dinda et al., 2026).
Versioning Complexity	18/39	API versioning was identified as challenging, particularly maintaining backward compatibility while evolving services (Dileep, 2025)
Operational Overhead	22/39	Microservices introduce operational complexity (monitoring, logging, tracing) not present in monolithic OOP systems (Sidat & Indika, 2022).
Learning Curve	15/39	Developers require training in both OOP and distributed systems concepts, creating a learning curve (Dinda et al., 2026)

In Tables 8 and 9, benefits and challenges were quantified based on the 41 and 39 studies that reported respectively. For benefits, counts are relative to the 41 studies. Overall, Improved Modularity and Enhanced Testability were the most frequently discussed OOP-related benefits, appearing in 31 and 28 out of 41 studies respectively. For challenges, Network Latency faced the highest challenge

with 27 out of 39 reporting limitations, whereas Learning Curve was less emphasized with the challenge of 15 out of 39 reports

RQ3: Design Patterns for Integration

The summary of Design Patterns Integrating OOP with Microservices is shown in Table 10.

Table 10: Design Patterns Integrating OOP with Microservices

Pattern	OOP Principle	Microservices Application	Frequency
DDD Aggregates	Encapsulation, SRP	Bounded contexts define service boundaries	18/35
Repository	DIP, Abstraction	Abstracts data access, enables caching/sharding	22/35
Factory	DIP, Polymorphism	Encapsulates service/client instantiation	14/35
Strategy	Polymorphism, OCP	Enables interchangeable algorithms within services	12/35
CQRS	SRP, Separation of Concerns	Separates read/write for independent scaling	16/35

Discussion

This scoping review indicates that Object-Oriented Programming (OOP) remains relevant to microservices and cloud-native architectures when its principles are adapted from the class level to the service level. Encapsulation corresponds to service boundaries and controlled APIs, while SOLID principles and patterns such as Repository, Factory, Strategy, CQRS, and API Gateway support modularity, testability, flexibility, and scalability. The findings particularly emphasize the need to balance the Single Responsibility Principle with operational realities. Excessive service fragmentation can increase network calls, latency, and management complexity; therefore, services should represent cohesive business capabilities while remaining sufficiently independent for deployment and scaling. Similarly, Dependency Inversion can reduce dependence on specific databases, message brokers, and external APIs by promoting abstractions and event-driven communication.

However, the evidence base remains limited. Only 6 of the 47 reviewed studies (12%) reported quantitative metrics, restricting strong conclusions about the effects of OOP on performance, scalability, and maintainability. The review is also limited by its focus on English-language peer-reviewed publications, differences in study designs and evaluation metrics, and the rapid evolution of cloud-native technologies. Consequently, the findings should be regarded as indicative rather than definitive.

For practice, OOP principles should guide service decomposition and API design without encouraging over-fragmentation. Appropriate design patterns, together with monitoring, logging, and distributed tracing, can help manage the complexity of microservices. Future research should prioritize quantitative comparisons of OOP-based and alternative microservices implementations, longitudinal case studies, automated assessment of SOLID adherence, security evaluations, and investigations

into OOP's application in serverless, edge, and WebAssembly environments. Overall, OOP remains a useful foundation for microservices, provided its principles are adapted to distributed-system constraints and supported by stronger empirical validation.

CONCLUSION

This scoping review synthesizes evidence from 47 studies to evaluate the application of OOP design principles in microservices and cloud-based software architecture. Findings indicate that OOP principles—particularly encapsulation, SOLID guidelines, and design patterns—remain relevant and beneficial for microservices design, providing conceptual foundations for modularity, testability, and loose coupling. However, distributed environments introduce challenges (network latency, data consistency, operational overhead) requiring reinterpretation of OOP principles at service rather than object level. Major contributions include: (1) Scoping Synthesis: A comprehensive review of OOP in microservices (2) Evidence-Based Framework: Identification of five design patterns (DDD Aggregates, Repository, Factory, Strategy, CQRS) that successfully integrate OOP with microservices. (3) Research Gaps: Documentation of significant empirical gaps, with only 12% of studies including quantitative validation, and (4) Practical Guidance: Reinterpretation of SOLID principles for distributed systems, aligned with cloud-native best practices. We conclude that OOP principles provide valuable foundations for microservices architecture but require adaptation to distributed contexts. Future research should prioritize empirical validation, longitudinal studies, and integration with emerging technologies to advance evidence-based software architecture.

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