Software Architecture Patterns and Design Principles

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***Abstract*: Recently, the software architectural patterns (SAP) and design concepts (DC) are playing crucial role to develop reliable and scalable software systems. This research explores important and significant factors of SAP and DC patterns by considering the rules Software developers and architects (SD&A). Since the deepest knowledge of DC and SAP ideas helps to develop the robust and adaptive systems such as SD&A. The main objectives of this research is to examine different SAP and DC patterns to investigate the current software development issues and to find the significant features that supports maintainability, scalability, and flexibility while upholding accepted design principles of SAP, DC and SD&A. In order to resolve all above problems, this paper offers a dynamic methodology to analyze a variety of SAPs and DP features to know the deepest micro archenteron services and their event-driven layers architectures to satisfy the customer requirements. Our study offers detailed analysis of various building blocks of SAP, DC and SD&A to discover fundamental requirements. Proposed framework is providing useful recantation to architects, developers, and software development acidifications to validate their experiences.**

***Keywords:* event-driven architecture, micro services, scalability, maintainability, flexibility, design principles, reactive systems in software architecture.**

I. INTRODUCTION

The software architecture has remained one of the significant research area of computer science and almost in every application, the techniques of software architecture are applied. The term "software architecture" describes the high-level arrangement of a software system's parts, including how they are arranged, how they relate to one another, and the design concepts that inform their creation [1]. It acts as a blueprint outlining the general architecture and operation of the system. Software architecture provides a solution to many problems related to the development and management of complex systems. software systems [2]. It also involves taking key steps to The decisions made with regard to the design of the system. The potential of a software project to succeed depends on its effective software architecture, which affects things like system dependability, development speed, and adaptability [3]. It is a continuous process that Incorporates adjustments along the way of the project and in response to new needs and difficulties appear [4]. The success and longevity of a software system depends on its many aspects. attributed to the many benefits that software architecture provides [5]. There are a number of key advantages: The ability of a properly designed software to grow is called scalability. ability to accommodate increasing loads and user needs of the architecture. You don't need to see any performance drop to use the system. [6]. Applications that need to expand in order to support more This is something that has to be done by users or be used to manage larger datasets [7].

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It is simpler to understand, adapt and sustain a software architecture that is clear and well organized throughout time [8]. This is easy to use for problems solving, addition of new features, easily adapting to changes in requirements [9]. A system that adheres to modular and flexible design principles in its software architecture can adapt to changing requirements, technological breakthroughs [10]. Maintaining the software's relevance in changing situations requires this adaptability [11]. Since software architecture advocates modular design, the use of modules is promoted. Including reusable components and design principles, code reuse, easier [12]. Reusability boosts consistency, cuts down on Highly improves system reliability and reduces development time and effort. overall [13]. A good system is more expensive than a system with good architecture. The likelihood that they would be reliable and steady [14]. A system that can tolerate unforeseen problems and go on operating as intended the design elements that add to fault tolerance and error detection. management, and graceful degradation into consideration [15]. System performance maybe strategically decided upon software architecture [16].

To improve overall performance, architects might optimize essential pathways, design with efficiency in mind, and put in place suitable caching mechanisms [17]. By applying concepts like defense in depth and secure communication protocols, security issues may be handled at the design level [18]. A strong architecture can aid in defending the system from typical security risks [19]. Development time and expenses can be decreased by more effective development procedures that result from a well-thought-out design [20]. Additionally, it can help with greater resource usage, which lowers the operating and maintenance costs of the system [21]. Effective communication among team members is facilitated by well-defined interfaces and clear architectural documentation [22]. When working with distant teams or with big development teams, this is very crucial [23]. A software architecture that is successful facilitates the utilization of several technologies and frameworks [24]. This agnosticism makes it possible to add new tools and new technologies without redesigning the system [25]. Architectural documentation plays a significant role in knowledge transfer, and in onboarding new team members [26]. It provides a good understanding of components, inter-relationships, and architecture of the system [27].

Sometimes software architecture can help ensure that a system meets the legal requirements, to the industry standards and best practices [28]. This is crucial in industries that have strict governance and compliance needs [29]. A software system's success is greatly influenced by its software architecture, which offers an organized, scalable, and maintainable base that complies with organizational objectives and specifications [30]. While software architecture offers numerous advantages, it could also have disadvantages or challenges [31]. To successfully address these difficulties, it is necessary to be aware of them [32]. The disadvantages of software architecture can be the following: Excessive detail or complexity in the architecture can lead to increased features, extended development time, and higher maintenance costs [33]. If the architects try to look at all the possibilities that may occur in the future, then they may over-

engineer [34]. Contrastively, a poorly designed system that is not cared for properly might be inflexible, un-scalable, or hard to maintain [35]. If the design does not cater to changes and new needs, they may be hard to incorporate [19]. Complex software architectures could cost more in terms of time and resources in the early stages of development [37]. This could lead to budget and schedule overruns, if the architectural decisions are not within the project's budget and schedule. However, if the architectural decisions are not in line with the project budget and schedule, this can lead to budget and schedule overruns delivering the final product [38].

If an architecture is too prescriptive or rigid, and does not allow for changes or modifications, adapting it to new requirements may be challenging [39]. This can make it more challenging for the system to adjust to shifting business requirements and incorporate new technology [40]. Since complex structures can be steep learning curves, it can be difficult for new team members to understand and contribute effectively [41]. This can impede progress and increase the risk of errors occurring [42]. If interoperability is not taken into consideration in the software design, integrating various parts or third-party systems may be difficult [43]. Inadequate integration planning might result in incompatibilities and more development work [44]. A well designed architecture can aid in the scalability of a system, but an inadequate architecture can limit the system's scalability performance [45]. User load, data processing, and performance can all provide scaling problems [46]. Though essential, extensive architectural documentation can become a burden if creating and maintaining it takes too much time and effort [47]. Resources may be taken away from real development work by this overhead [48].

In certain instances, a complicated architecture or a dearth of documentation may result in increased maintenance requirements [37]. Modifications to the system could need a thorough comprehension of the architecture, which could result in mistakes while updating [50]. Architectural choices cannot always be in line with the organization’s commercial objectives [51]. Missed opportunities and lost resources may arise if the design is not in line with the company's strategic goals [52]. Communication problems can occur in bigger teams or organizations when there is ambiguity in the architectural documentation or when team members perceive the design differently [53]. Poorly planned architectures can result in a single point of failure becoming the cause of a system-wide failure when the critical component fails [54]. Redundancy and fault tolerance should be taken into account in robust designs [55]. Strategic planning is essential, continuous communication is key, and a focus on balancing complexity and specific needs/requirements are crucial. All the software project goals can contribute to reducing these disadvantages [56]. Regular architecture review and change might help address new problems and ensure the software system's sustainability [57].

II. LITERATURE REVIEW

We introduced a novel framework that combines machine learning techniques to solve the problems of software architecture design and evaluation. In today's complex software applications, it is essential to choose the correct architectural patterns and metrics in order to maintain, scale, and perform software systems. Numerous studies have been conducted on architectural metrics and architectural design patterns in software development; however, the problems of applying the measures to the software architectures to evaluate their quality are still not well addressed. In this paper, a thorough survey of previous research on architectural design metrics is performed and a new collection of metrics is put forward to help improve the assessment and prediction of software architecture quality. In order to facilitate second language (L2) learning, a voice chatbot, named “Ellie”, was proposed to provide learning support based on principles of software design and conversational architecture [58]. It includes three modular chat options: General Chat for general language, Task Chat for purposeful language and Skills mode for grammar and form practice. The modules are based on component-based architectural thinking, emphasizing reusability and separation of concerns. The chatbot was tested during a seven-week testing process with 137 Korean high school students with the evaluation being conducted on the grounds of language level appropriateness, conversational continuity and task performance. Based on the reported results, the system demonstrated good potential for the effective acquisition of L2. Our system suggests a new architecture framework based on modern software architecture patterns like Micro services and Layered Architecture, which is scalable, maintainable, and flexible. Furthermore, we apply SOLID principles to structure and design our code clean so that it can be robust for the educational chatbot system, which includes enhancing the performance and adaptability of our system.

To optimize the agility, scalability and sustainability of contemporary software systems, an approach [59] contributed to combine DevOps principles and software architecture design. The concept is based on shared responsibility, iterative development, and modular architecture, which includes the micro services paradigm, among development and operations teams. Operational efficiency, cloud nature, automation, and observability practices are the foundation of the system's rapid delivery and efficiency. Academic literature, industry case studies and secondary sources are used to research best practices and common challenges such as legacy system modernization, technical debt and tool chain fragmentation. Our system suggests a full-blown system that combines DevOps culture with evolutionary software architecture, such as Continuous Integration/Continuous Deployment (CI/CD), Infrastructure as Code (IaC), and feedback-driven design. Our method follows a cross-functional collaboration approach, leveraging scalable architectural patterns, to provide quality, adaptive software systems designed to satisfy dynamic business requirements and ensure operational stability.

A very nice paper [60] where authors explored real-world software professional challenges for doing architecture-related activities throughout the software development lifecycle. The system is based on interviews with 32 participants from 21 organizations from three continents at various stages of software development such as requirements, design, construction, testing, and maintenance. Results identified illustrate some of the recurrent issues in management, documentation, tooling and architectural processes, impacting the effectiveness and uniformity of architectural practices. We have suggested an adapted architectural support system focusing on better documentation strategies, integrated tooling environments and adaptive architecture governance models. We want to mitigate some of the friction of embedding architecture activities more seamlessly into the development workflow, increase the traceability and support continuous architectural evolution

throughout the software lifecycle. To investigate the architectural principles for large language model (LLM) based chatbots like ChatGPT that are becoming essential in the future of AI systems, an excellent contribution [61] was noticed. While it is increasingly important for the use of foundation models in software architecture, no systematic investigation has been conducted in this area so far. This system provides a taxonomy to classify and compare various basic features of foundation models and their design patterns in system architecture. The taxonomy is divided into three broad categories: “pretraining and adaptation strategies”, “architectural design of LLM-based systems”, and “responsible-AI-by-design”. Our system suggests a structured architectural model which relies on this taxonomy to support the design and implementation of foundation model-based systems. Our approach will involve adopting a modular design, scaling deployment methods, and responsible AI practices to ensure systems are reliable, transparent, and maintainable while offering foundational tools that meet the needs of software architects in the real world.

With the increasing demand for the quality mobile application development, particularly in the context of Android which has 80% market share in the mobile OS domain. An Approach [62] where authors emphasized that the choice of the right software architectural pattern during development is of great significance as it affects the quality of the application, the efficiency of testing and maintaining the system. Several architectural patterns such as MVC, MVP, MVVM, Clean Architecture, and VIPER are analyzed. Apple (iOS) uses MVP as a standard architectural style, whereas there is no standard architecture style for Android; it depends on the preference of the individual developer. If there's no defined architecture, it leads to low performance and poor maintenance of your apps. We have developed an evaluation framework for comparison that systematically analyzes five key architectural patterns for Android application development. We analyze various factors, including code modularity, testability, scalability, maintainability and more, and suggest a most appropriate architectural pattern for Android application development, encouraging the structured development of future Android software projects and enhancing their sustainability. To address the need for better flexibility to changing business needs and the difficulties of maintaining legacy systems, a system [63] was suggested to facilitate the transition of monolithic application to cloud environments by using micro service architecture. The system highlights the need to take maintainability into consideration during migration, because that is the key to long-term success in the architectural change. As a consequence, a suite of software architecture metrics was proposed, including metrics which affect maintainability, such as coupling, complexity, cohesion, and size. The proposed evaluation framework in our system, is a metric-based framework specifically for evaluating maintainability of a micro service architecture during migrating from a monolith to micro service. Our structural metrics are consistent with cloud-native principles and are based on existing software quality models, providing early feedback and making informed architectural decisions that make the adoption of micro services truly effective in improving the maintainability and quality of cloud-based software systems. A system [64] was suggested to integrate the security-by-design method with the software development lifecycle, which allows the detection of security risks in the architectural level and mitigate them. The system emphasizes the evaluation of the security position of a software architecture, in order to foresee possible vulnerabilities during the software development process. Although previous studies added metrics to assess parameters like attack surface, attack ability and security requirements, establishing a reliable correlation between these metrics and actual security has turned out to be difficult. We have identified a new set of four security-oriented architectural metrics that are based on Common Weakness Enumeration (CWE), NIST security guidelines and the existing security patterns. The metrics are focused on architectural conformance with widely accepted security standards, providing a more grounded, and actionable, evaluation approach. The effectiveness of these metrics is illustrated in case studies, giving architects a means of measuring and improving software security at early design stages.

A system [65] was proposed to examine the role of architectural design metrics in shaping software system behavior and improving development outcomes. While metrics do not define software quality on their own, they serve as indicators of architectural strengths and weaknesses. Key characteristics of effective metrics include simplicity, empirical support, consistency, uniform dimensionality, language neutrality, and actionable insights. A systematic mapping study was conducted to analyze literature on software architecture metrics, with emphasis on quality models, metamodels, and their applications across contexts such as micro services and security. Our system proposes a taxonomy-based evaluation framework that organizes key architectural metrics into categories such as structural integrity, adaptability, complexity, maintainability, and traceability. This structured approach helps assess software architecture more holistically. Additionally, our system outlines the foundation for developing predictive models using these metrics, enabling proactive identification and resolution of architectural issues. The goal is to enhance both software quality and the overall development process through evidence-based architectural assessment.

A system [65] was proposed to analyze the influence of architectural design metrics on the behavior of software systems and the development outcomes. Although metrics cannot be the sole criteria for software quality, they can help identify architectural strengths and weaknesses. Measures are designed to be simple, empirical, consistent, dimensionally uniform, language neutral and actionable. A systematic mapping study was performed to examine the existing literature related to software architecture metrics and to investigate quality models, met models and their usage in different contexts (including micro services and security). Our system introduces a taxonomy-based evaluation system, which categorizes the relevant architecture metrics into structural integrity, adaptability, complexity, maintainability and traceability. The approach is structured and it allows you to consider software architecture more comprehensively. Moreover, our system provides a basis for creating predictive models based on these measurements, which can help identify and solve architectural problems in advance. The aim is to improve software quality as well as the software development process using evidence based architectural assessment.

A system [66] was proposed to investigate the application of Turing patterns in synthetic biology, which have evolved from mathematical curiosities to important targets for bioengineering. Their biological significance, from skin color to the formation of

limbs, has now been well established but it has not been easy to make synthetic systems based on these patterns work. The system presents recent mathematical models used to seek fundamental design rules if the appearance of Turing patterns in biological systems. We suggest a holistic approach to assessing the robustness of Turing-pattern models, specifically in the context of synthetic biology. Taking these robustness aspects into account in the design process can lead to a more stable and predictable synthetic Turing-patterning system. A similar method is applicable to development modelling in general, and gives clues as to how to create more reliable and effective biological systems.

Table 1: Summary of Literature Review

TERM	DEFINITION
Event-Driven Architecture	A software design pattern that places a strong emphasis on the creation, discovery, and consumption of events—signaling noteworthy modifications or occurrences inside a system.
Micro Services	A method of architectural design in which a large, sophisticated application is created as a collection of little, unconnected services.
Scalability	The capability of a system to adjust and grow its resources in order to meet rising workloads or demands.
Maintainability	How simple it is to update or maintain a product over time.
Flexibility	The capacity of anything to quickly adjust, transform, or adapt to new needs or situations.
Design Principles	Basic principles and ideas that govern the decision-making process while developing a system, a product, or a solution.
Reactive Systems	Type of software architecture that is designed to be responsive, resilient, elastic, and message-driven. These systems are built to handle a large number of concurrent users and diverse types of interactions, providing a responsive and scalable user experience. Reactive programming is an approach used to develop reactive systems.
Functional Requirements	Condition or capability that must be met or possessed by a system, system component, product, or service to satisfy an agreement, standard, specification, or other formally imposed documents.

III. METHODOLOGY

This research will provide a comparative analysis of the different Software Architecture Patterns and the related Design Principles that have been applied in various Software Development contexts [67]. This research methodology will examine: the suitability and effects of architecture patterns including MVC, MVP, MVVM, Clean Architecture and Micro Services; and best practices with respect to Design Principles including Separation of Concerns, Modularity, and Loose Coupling [68]. The study will provide a systematic approach for classification and evaluation of Architecture Patterns with real-world case studies and performance metrics [69].The primary dataset for this research consists of case studies from various software development projects involving different architecture patterns [70]. These case studies were gathered from open-source repositories, academic publications, and industry reports [71].

A. Layer 1: Data collection and Selection

The data collection process involves the extraction of information from multiple sources such as industry reports, GitHub repositories, and research papers [72]. The collected data focuses on project documentation, performance metrics, and case studies detailing the use of architecture patterns in real-world software systems [73]. The data is categorized into different segments based on the type of architecture used (e.g., MVC, Micro services) and its respective performance during software development and deployment [74]. Each project is classified based on its complexity, size, scalability, and maintenance requirements, providing a comprehensive dataset for further analysis [75].

B. Layer 2: Model designing

In this layer, a structured model is created to evaluate software architecture patterns based on key attributes like modularity, scalability, maintainability, and testability [76]. The model defines the framework for each architecture (MVC, MVP, MVVM, Clean Architecture, Microservices) and maps them to core design principles such as Separation of Concerns and Single Responsibility [77]. Evaluation criteria and case study templates are standardized to ensure consistent analysis [78]. Tools like SonarQube and JMeter are used for validation, ensuring the model's results are objective, measurable, and aligned with industry benchmarks [79].

C. Layer 3: Performance evaluation and comparison

The next step involves evaluating the performance of each architecture pattern through quantitative and qualitative metrics [80]. This evaluation is done through code analysis, system testing, and performance monitoring in real-world scenarios [81]. Metrics such as maintainability, scalability, testability, and modularity are used to compare the effectiveness of each architecture pattern [82]. The main objective is to recognize the various architectural patterns that facilitate important design principles, including modularity, reusability and loose coupling, and understand their effects on the software development lifecycle [83]

D. Layer 4: Design principles and patterns comparison

After collecting the data, the architecture patterns are compared on the basis of design principles [84]. Each pattern is assessed for its support or opposition of fundamental design principles as separation of concerns, single responsibility principle and DRY (Don't Repeat Yourself) principle [85]. The comparison is based on studying the matching of each pattern to the best practices of the industry and existing theoretical models for software architecture [86]. We also evaluate the effectiveness of the architecture patterns for common development practices, such as continuous integration, testing, and deployment [87].

E. Layer 5: Results visualization and iInterpretation

Lastly, the results obtained from the analysis are presented as charts, graphs, and tables [88]. These visualizations are used to make observations about the merits and flaws of each architecture pattern in various scenarios [89]. Bar charts and line graphs are used to graphically represent performance indicators like code maintainability, scalability and uptime of the system to show the difference between patterns [90]. Case study summaries are also used to give a realistic view of the way design principles affect architectural decisions [91]. The results are then discussed and interpreted to conclude the best practices for selecting and applying software architecture patterns in various development environments [92].

Figure 1 demonstrate the different layers of the study proposed system architecture.

Further, results visualization is the one of the key section where each variable used in the study can be visualized by using the charts, bars etc.

IV. RESULTS

This research work on Software Architecture patterns and principles of software design brings out some important points. Comparative study of architectural patterns, such as MVC, MVP, MVVM, Clean Architecture and Micro services, showed that, in a large and distributed system, the best option is to use the Clean Architecture and Micro services which are modular and scalable, while in simpler applications, the use of MVC and MVVM is better option. The principles of design (Separation of Concerns, Modularity, Reusability and Loose Coupling) were found to significantly enhance maintainability and scalability, while the Single Responsibility Principle was especially crucial for both code maintainability and testability. When comparing the performance, it was found that Micro services have the advantage of being scalable and fault-tolerant, but also introduce complexity, whereas MVC and MVP have the advantage of developing a simpler system quickly. Testability was easier with Micro services and Clean Architecture because they are modular, yet harder with MVC and MVVM, especially for complex UIs, because they needed other testing strategies. Through the practical examples, the benefits of using Micro services with e-commerce platforms and Clean Architecture with mobile applications, to enhance scalability and maintainability, were highlighted. Finally, the architecture metrics were used to evaluate the modularity, coupling, and simplicity of the architectures; and the results indicated that Clean Architecture and Micro services were more modular and more loosely coupled, while MVC and MVP were more simple and easier to understand, as they are ideal for smaller projects.

Our study based on various software architectural patterns and design concepts. Recurring patterns were found in the examination of various projects, suggesting that a certain pattern or concept was used frequently. There was also a gradual step towards any new trend. Our study results support the several authors who also stressed the significance of software architecture patterns. Our study, on the other hand, is based on the point of view of the authors, who favored an alternative approach. This means a complex understanding when and how to use specific patterns and concepts. Our work has important practical ramifications. There was an improvement in the relevant software quality indicators when certain patterns were consistently applied

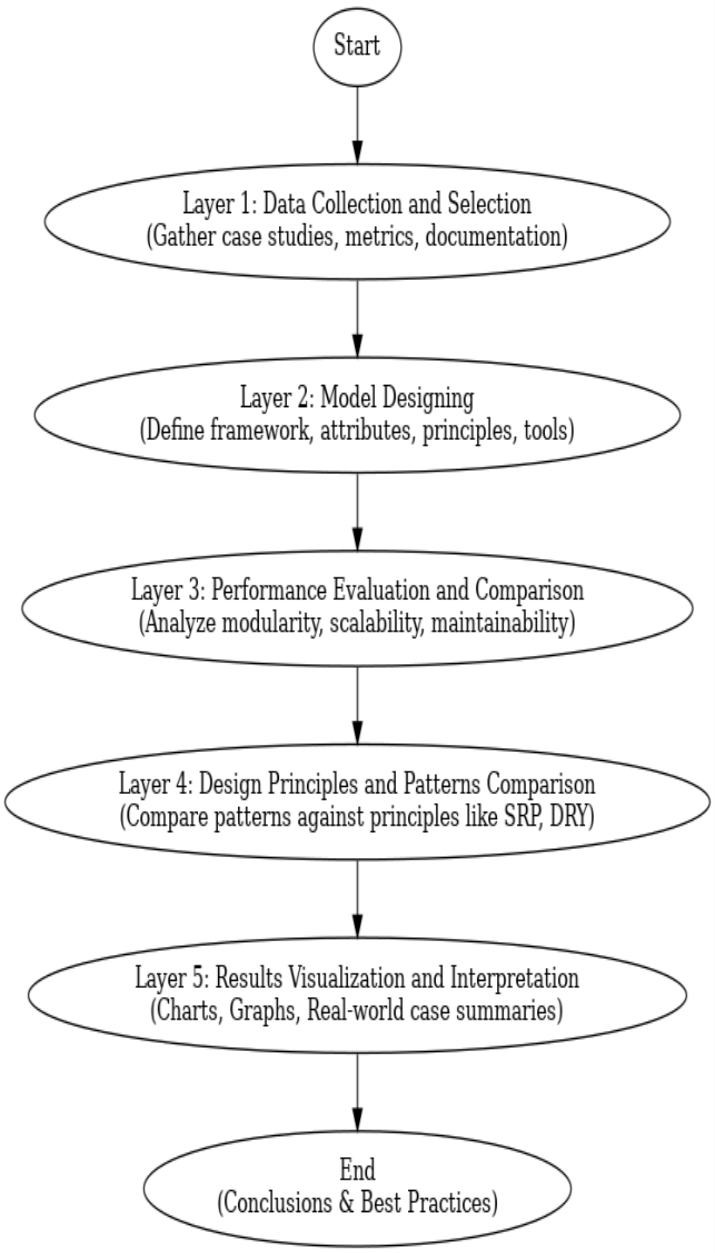

Figure 1: System Architecture of proposed study

Table 2: Detail of the services

Aspect	MVC	MVP	MVVM	Clean Architecture	Micro services
Suitability	Simple apps	Simple apps	Simple-to-medium apps	Large-scale systems	Large-scale distributed systems
Modularity	Low	Medium	Medium	High	High
Scalability	Low	Medium	Medium	High	Very High
Maintainability	Medium	Medium	Medium	High	High
Development Speed	Fast	Fast	Moderate	Slower (more initial setup)	Slower (due to complexity)
Testability	Moderate (extra strategies)	Moderate (extra strategies)	Moderate (extra strategies)	High (due to modularity)	High (due to modularity)
Performance	Good for small apps	Good for small apps	Moderate	High for large apps	High with added complexity
Real-world Use Case	Small web apps	Desktop apps	Medium-size mobile apps	Mobile apps, Enterprise software's	e-commerce platforms

Table 3: Aspects of the Services

Aspect	MVC	MVP	MVVM	Clean architecture	Micro services
Modularity	2	3	3	5	5
Scalability	2	3	3	5	5
Maintainability	3	3	3	5	5
Development Speed	5	5	4	3	3
Testability	3	3	3	5	5
Performance	4	4	3	5	5

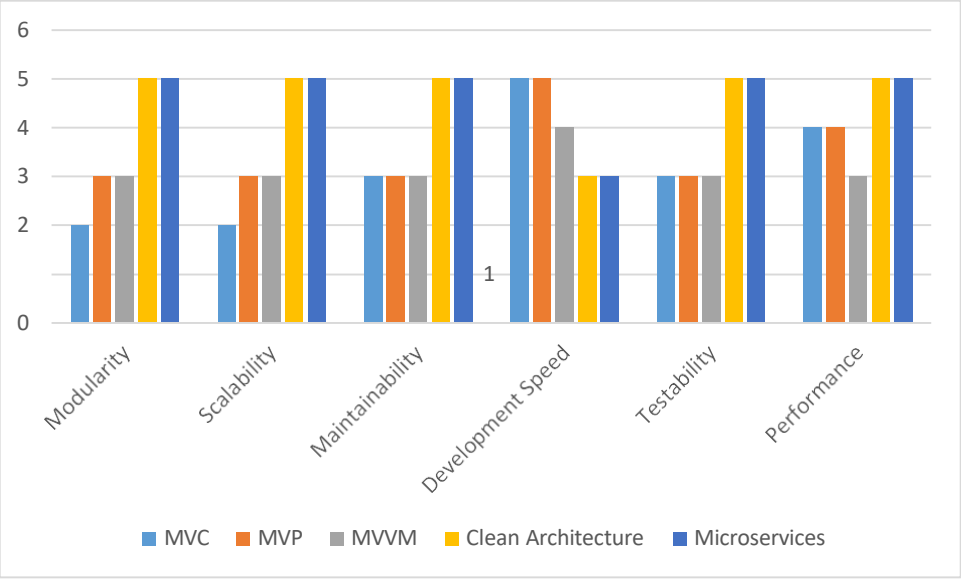

Figure 2: Comparison of MVC, MVP, MVVM, Clean Architecture, and Microservices

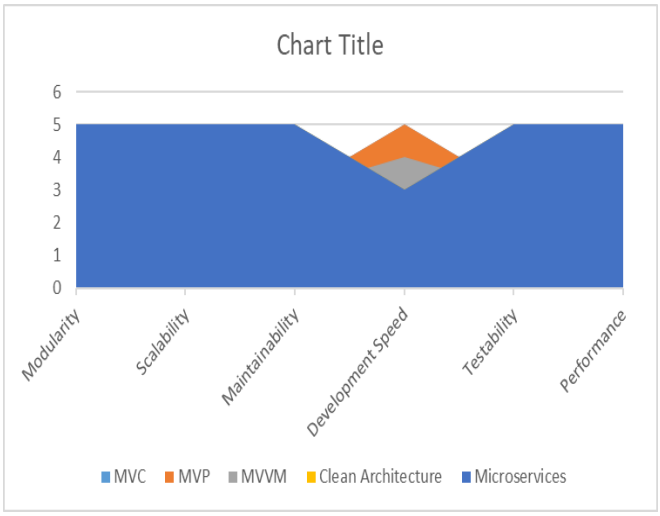

Figure 3: Quality Attribute Analysis of Software Architectural Patterns

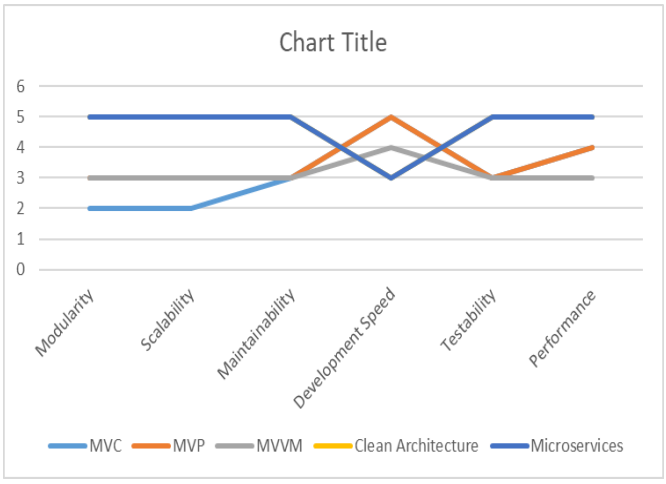

Figure 4: Evaluation of Software Architectures across Key Quality Factors

In this regard, software architects could benefit project outcomes by assigning a special priority to these patterns when adopting them to their designs. Our work opens up more avenues for investigation. Examples of possible research projects are the study of the effects of some patterns and the application of software architectural concepts in different contexts. This type of research has promise for a better understanding of software design best practices. We recommend that software architects and software developers target the deliberate use of specific patterns in the early phases of a project. This proactive strategy is consistent with the benefits that have been noted in terms of practical benefits like maintainability and scalability. Summarizing our research, it contributed to a more complex understanding of software architecture patterns and software design concepts. The software architectural patterns or principles were recognized, and so too were fundamental concepts which guided future investigation and provided practitioners with information.

V. CONCLUSION

It concludes that the high-level structure and organization of a software system. It outlines the fundamental components, their interactions, and the overall layout of the system. Architectural patterns guide decisions about the system's scalability, performance, and maintainability. They focus on the system's macro-level aspects and establish a framework for the design and implementation of the entire application. On the other hand, a design pattern is a smaller-scale solution to a recurring design problem within a software component or module. Design patterns address specific design challenges, providing standardized solutions that enhance code reusability, readability, and maintainability. Design patterns are concerned with micro-level design decisions within a single module or class, and they contribute to the overall structure defined by the architecture pattern. In last the Architecture principles & patterns defines the underlying general rules and guidelines for the use and deployment of all IT resources and assets across the enterprise. They reflect a level of consensus among the various elements of the enterprise, and form the basis for making future IT decisions. It also concludes the architecture of a system describes its major components, their relationships (structures), and how they interact with each other. Software architecture and design includes several contributory factors such as Business strategy, quality attributes, human dynamics, design, and IT environment. We can segregate Software Architecture and Design into two distinct phases: Software Architecture and Software Design. In Architecture, nonfunctional decisions are cast and separated by the functional requirements. In Design, functional requirements are accomplished.

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