**Domain-Driven Design in Cloud Computing A .NET and Azure Case Analysis**

Jordan Jordanov1, Pavel Petrov1, Ivan Kuyumdzhiev1

*1University of Economics - Varna, Varna, Bulgaria*

*Abstract –* This paper explores the integration of Domain-Driven Design (DDD) into the cloud computing components of the Microsoft ecosystem. The study aims to show a proficient methodology for constructing a software architecture that is capable of growing, easy to maintain, and efficient. The research was driven by the necessity to close the gap between theoretical principles of DDD and their practical implementations in cloud-native services. The research utilized a case study methodology to offer an empirical overview. According to the results, DDD can be classified as a vital consideration for the application and data layers of the overall Platform-as-a-Service and Infrastructure-as-a-Service cloud models. The study findings indicate that the utilization of DDD in cloud computing improves scalability, maintainability, and cost-effectiveness. The case study explores the potential of employing Domain-Driven Design (DDD) as a conventional approach to enhance the efficiency of software architecture in cloud environments.

*Keywords –* Domain driven design, cloud computing, case study, software architecture, Azure .NET.

1. **Introduction**

Domain-Driven Design (DDD) has become an important framework in the constantly evolving field of software development, enabling the creation of advanced applications DDD creates a collaborative environment by closely linking software design with the main business domain. This approach encourages technical and domain experts to work together in

DOI: 10.18421/TEMxx-xx

<https://doi.org/10.18421/TEMxx-xx>

**Corresponding author: -** ,

*affiliation*

**Email:** -

*Received: -----.*

*Revised: -----.*

*Accepted: -----.*

*Published: -----.*

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developing software that is flexible and can easily adapt to evolving business requirements. Although this approach shows potential, there is still a notable lack of research in practical studies that examine the relationship between DDD concepts and cloud development frameworks for constructing web, mobile, desktop or IoT applications. This paper aims to investigate the implementation of DDD concepts using .NET and their deployment on the Azure platform. This study aims to offer a comprehensive perspective on the strategic decisions, architectural elements, and results related to these integrations. To accomplish this, the study utilizes a research methodology that involves multiple use cases.

DDD provides a philosophy and a set of guidelines, including bounded contexts, and ubiquitous language. In addition, there are programing models like “Aggregates” and “Value objects” as well as patterns as Command Query Responsibility Segregation (CQRS) and Event Sourcing (ES). These principles are especially applicable to microservices, functional programming, and event driven development. In addition, an integrated test suite is supposed to guarantee the integrity of all of them.

Table 1 provides a fundamental classification of cloud computing, which presents various categories based on different levels of abstraction and customized service provision to meet specific operational needs.

*Table 1. Classification across some of the fundamental cloud services*

|  |  |
| --- | --- |
| Infra as a Service | Platform as a Service |
| Application | Application |
| Data | Data |
| Runtime | Runtime (Managed) |
| Middleware | Middleware (Managed) |
| OS | OS (Managed) |
| Virtualization (Managed) | Virtualization (Managed) |

From the models presented Platform as a Service (PaaS) and, to a certain extent, Infrastructure as a Service (IaaS) have become the focus areas for DDD. PaaS and IaaS offer customers frameworks that create, build, and manage applications. This eliminates the difficulties that come with developing and maintaining the underlying infrastructure. IaaS possesses inherent proficiency in managing elements such as networking, storage, servers, and virtualization. PaaS encompasses operating systems, middleware, and runtime environments, thereby assigning developers the task of managing applications and data. The significance of DDD concepts becomes apparent within these two fields.

The microservices architecture is defined by the process of breaking down applications into small, autonomous services, initiating the establishment of one of the cloud-native standards. Each microservice, which contains a specific business function, can be deployed, scaled, and maintained independently. This allows for the utilization of the natural flexibility and durability of cloud platforms. Microservices facilitate the implementation of continuous integration, continuous delivery, and dynamic resource allocation. As stated by the Cloud Native Computing Foundation (CNCF), microservices allow the creation of system components that are loosely connected, resilient, manageable, and observable. When used in conjunction with strong automation, they enable engineers to make significant and predictable changes frequently, with minimal effort. There are numerous scientific studies that have examined the leading corporations like Netflix and Uber. These companies are supporting online platforms, which are offering a wide range of services. The software responsible for these services frequently releases new versions, deploying thousands of instances on a weekly basis.

The primary objective of microservice architecture is to establish explicit and well-defined boundaries. This include identifying bounded contexts and associated aggregates, and determining the types of commands and queries that end users perform on the system. Bounded context (BC) is a fundamental concept in DDD that acts as a means of separating different components to enhance their ease of management and scalability. In addition, a BC emphasizes the importance of self-reliance by encompassing entities, repositories, factories, and application services. BCs are components of the solution architecture designed to address specific sub-domains that are logically separated. The degree of physical isolation introduces an additional level of intricacy, contingent upon factors such as precise specifications, codebase, and the size of the development team.

There is at least one aggregate present in BC. Aggregates are identified through thorough analysis sessions, typically leading to the recognition of different entities and value types that naturally form groups under the control of a main entity. When this kind of grouping happens, it signifies the demarcation of a collective, formed exclusively by business regulations. An aggregate function as a domain model by grouping multiple entities together under a single conceptual framework.

In order to design an approach for constructing aggregates and other DDD models, this study examines the practical aspects of using functional programming (FP). FP primarily focuses on two distinct features: maintaining the integrity of method signatures and ensuring referential transparency. The concept of method signature honesty ensures that a function's signature accurately and comprehensively represents all possible input and output values. Referential transparency guarantees that a function's output remains consistent for a given input, without any additional side effects. Furthermore, FP is supposed to the reduces code complexity, making it easier to understand and analyze logically. It also considered to simplifies unit testing and enhances the modularity and composability of software components.

The importance of immutability in FP is crucial, as mutable operations have the potential to introduce “dishonesty” into the code. The absence of clearness hampers our capacity to participate in rational reasoning, making the process of debugging more complex and creating barriers to multi-threading. Moreover, the utilization of FP is improved by the implementation of CQRS and the integration of fundamental domain logic. Railway-oriented programming, influenced by Scott Wlaschin, offers a more efficient method of structuring processes in contrast to conventional methodologies that involve lengthy and complex code blocks containing numerous "if/else" and "try/catch" statements. The functional approach employed in this context utilizes extension methods to enhance legibility by reducing redundant code and emphasizing the main logical sequence.

In this context, it is important to analyze the logic of the code in real time by putting the system under test (SUT). Unit testing for codebases of this nature primarily entails supplying input to functions and verifying the outcomes. To support these needs test doubles, particularly mocks, can be utilized to replace dependencies with unpredictable behavior, thus achieving the desired outcome. Unit testing offers a key benefit of ensuring the integrity of existing functionality while allowing for efficient modifications to code.

Based on a case study from the Computer Science department at North Carolina State University, unit testing is considered a crucial safeguarding measure. Within this framework, a key performance indicator (KPI) is code coverage, also known as test coverage. This metric quantifies the extent to which the source code of a program is tested by a particular test suite. Code coverage is expressed as the ratio of the number of lines of code covered by tests to the overall number of lines in the codebase, visually represented as:

***Code coverage = Lines of code covered / Overall number of lines***

This ratio provides a numerical value that reflects the thoroughness of testing and helps identify untested parts of the code. High code coverage is often associated with higher software quality, as it indicates that a significant portion of the code has been executed during testing, potentially uncovering defects and ensuring that the software behaves as expected under various conditions. However, achieving 100% code coverage does not guarantee the absence of bugs, as it does not account for the quality or comprehensiveness of the tests themselves. Nonetheless, striving for higher code coverage can contribute to more robust and maintainable code by encouraging comprehensive testing practices. In summary, code coverage serves as a useful benchmark for evaluating the effectiveness of test suites and guiding the development process toward better software reliability and performance.

1. **Methodology**

The aim of this study is to explore and give in-depth understanding of the software development with DDD, CQRS and ES patterns via .NET and Azure technologies. To reach this goal, the selection of an appropriate research approach is an important step. Regarding the uncertainty and a lag of research for the implementation of the DDD concepts, this goal of this study is to fill this gap and show strong and reliable development processes. To approach this goal, case study research was deemed as an appropriate research method. Case studies, representing qualitative research methods, are commonly used within the computer and social science. According to XXZ, the case study design may be chosen when the selected case represents a critical case in testing a well-formulated theory with clearly defined propositions, which is going to be shown in the 3rd sub-section of this chapter. The nature of the current case study is confirmative (explanative). The purpose is testing the DDD theories that have been deducted from preview’s research.

***2.1. Tools & Technologies***

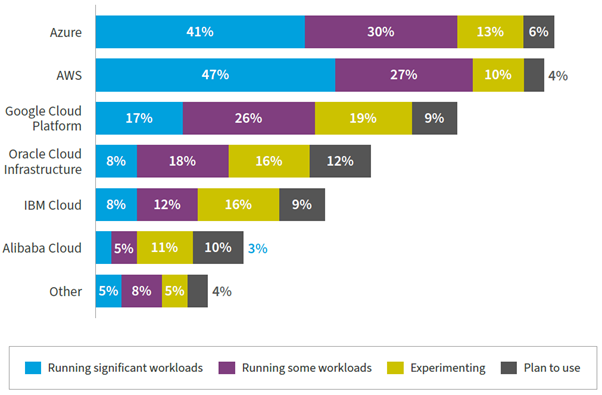
The .NET is widely acknowledged as a prominent option for developing scalable and robust corporate applications. Based on statistics provided by Techempower [], it has been observed that ASP.NET exhibits superior efficiency and performance compared to several alternative web application platforms and full-stack frameworks, given in Table 2.

*Table 2. Comparison of server technologies*

|  |  |  |
| --- | --- | --- |
| Technology | Programming language | Processed requests per second |
| ASP .NET Core | C# / .NET | ~300 613 |
| NodeJS | Javascript / C++ | ~200 123 |
| Gin | Go | ~150 230 |
| Symphony | PHP | ~100 234 |
| Spring | Java | ~80 954 |

ASP.NET Core is noted to be faster than Node.js, Gin, Symphony, and Spring. This significant performance advantage showcases ASP.NET Core's efficiency and capability in handling high-performance web applications. Microsoft has outlined a strategic plan [] for the future development and maintenance of .NET, guaranteeing regular upgrades and expanded library support which boasts 5.7 million monthly active developers within the “Visual Studio family” []. Moreover, .NET Core has been recognized as the *"#1 Most Loved Framework*" for three consecutive years (2019, 2020, 2021) according to Stack Overflow surveys []. The .NET ecosystem is highly active in the open-source space, with its GitHub repository being ranked among the "*Top 30 Highest Velocity OSS Projects*." According to data conducted by Github, C#, a primary language in the .NET ecosystem, is listed among the "*Top 5 Languages*." This ranking indicates C#'s popularity, highlighting the widespread adoption. Approximately "40% of New to .NET are Students," as indicated by a download survey. This statistic highlights the growing interest and adoption of the .NET framework among the academic’s fields, ensuring innovations within the ecosystem. Additional factors include the use of the supplemental libraries such as *Minimal API, EntityFramework, MediatR, Optional, Marten, SignalR, AutoMapper, Serilog, Stylecop, Swagger, FluentValidation, xUnit, Autofixture, Moq and Shouldly*. This interoperability further enhances the esteemed status of .NET.

Microsoft Azure, a well-known provider of cloud services, offers extensive support for .NET applications via Integrated Development Environment (IDE) like the Visual Studio. This integration enhances the development experience and ensures interoperability within the broader Microsoft ecosystem. Figure 1 obtained from the "Flexera's 2023 State of the Cloud Report," [] showcases the use trends of different public cloud providers across enterprises.



*Figure 1. Cloud service providers used by organizations in the public sector.*

The findings derived from a sample of 750 participants indicate that Azure has emerged as a prominent player in the cloud services market. Specifically, 41% of firms are utilizing its platform to execute substantial workloads, 30% are using it for certain tasks, and approximately 13% are currently in the testing phase. According to data from Microsoft, Azure has demonstrated a substantial growth rate of 31% in the quarter ending March 2024. Azure's extensive network of over 60 data centres surpasses the offerings of other cloud providers, reinforcing its dominance in the market. Notably, major clients such as Samsung, Boeing, eBay, and BMW rely on Azure's services. Based on the collected data, it can be deduced that the use of .NET and Azure is a favourable choice for performing a thorough analysis of the implementation of DDD.

***2.2. Case Selection***

The process of case selection and data collection plays an integral role in establishing the empirical foundation of this research. This study is motivated by multiple cases, specifically drawing on Microsoft reference applications „eShopOnContainers“ [] and „eShopOnAzure“ []. The emphasis on functionalities related to order administration serves as a framework for streamlining the more complex aspects of enterprise-level systems. Below, we present three relevant demonstrations for these systems.

*Table 3. Cases of enterprise-level systems*

|  |  |  |
| --- | --- | --- |
| Case | System | Description |
| A | Order Management | A digital system that oversees the entire lifecycle of an order. It centralizes the management of all sales channels, ensuring precise picking, packing, and shipping processes. |
| B | E-Commerce | An online platform that enables the exchange of products and services over the Internet. These technologies consequently improving convenience for both consumers and enterprises. |
| C | Supply Chain Management | Software platforms for real-time visibility, ensuring efficient flow of goods, information, and finances. |

The process of data collection aligns with the functional and non-functional requirements identified through a literature review of existing academic research. This case study primarily emphasizes a analysis of the implementation procedures related to the registration of order records and the subsequent modifications made by end users.

***2.3. Conceptual framework***

Within the conceptual framework illustrated in Figure 3, DDD is emphasized as a fundamental paradigm, focusing on domain-centric constructs such as BC and UL, supported by extensive research in the field. The CQRS pattern complements this approach by promoting the separation of read and write processes, enhancing system scalability and maintainability. Additionally, ES provides a robust mechanism for capturing state changes over time, ensuring a comprehensive audit trail. TDD is incorporated to ensure functional reliability and code quality. This study explores these methodologies within a cloud-native environment, employing a case study approach to offer empirical insights into their feasibility and effectiveness.



*Figure 3. Conceptual framework model of the DDD Approaches in the Cloud Environment*

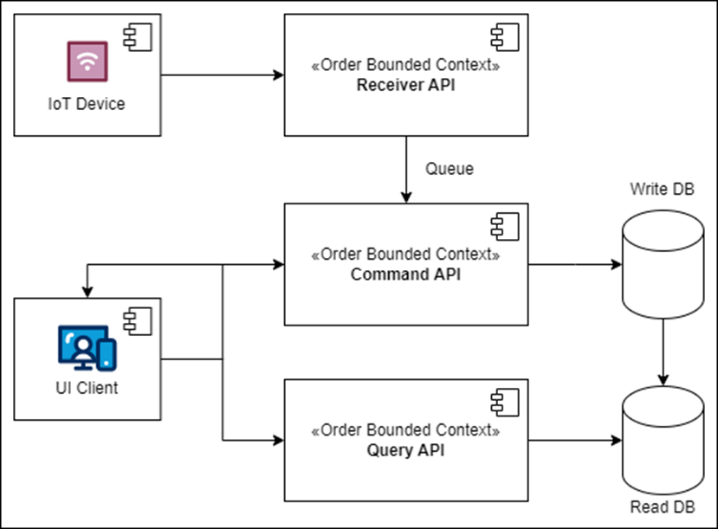
The case study methodology is a viable strategy in the scenario, as it aligns with the research topic about the impact of DDD on cloud solutions. Case study research is often regarded as a valuable method for facilitating the establishment of a comprehensive knowledge of a particular phenomenon, aligning with the aims of the present study.

1. **Results**

This section seeks to investigate the effectiveness of BC, CQRS, UL and ES as part of the DDD in improving system modularity, scalability, and maintainability. Addressing the research question will not only provide valuable insights to the academic discussion but also establish clear programming principles. In this context, the results of this study aim to provide valuable direction for software developers and architects in designing and implementing suitable data structures and algorithms.

***3.1. Applying Bounded Contexts to Microservice Architecture***

The concept of a BC refers to a well-defined area of responsibility that is delineated by a distinct border, which strongly aligns with the fundamental principles of microservice design. Within a business domain, BC serves as a container for a fundamental business idea, connecting functionality and data models. As seen in Figure 4, the design of the system is characterized by the presence of three primary microservices, namely the Receiver API, Command API, and Query API.



*Figure 4. UML Component Diagram that illustrates the structure and relationships of microservices within their respective BC*

These microservices encapsulate separate and different duties within the order management BC. The Internet of Things (IoT) devices are integrated with the Receiver API, guaranteeing the effective management and queuing of incoming requests for further processing. The Command API is responsible for coordinating the persistence of order data and ensuring consistent interactions with the writing database. On the other hand, the Query API enables the retrieval of order information by directly integrating with the read database. These two APIs provides service to user interface (UI) clients. The practice of segregation cultivates a system architecture that is modular and easy to maintain, hence enhancing its resilience against the inherent intricacies involved in order management operations. The units of work demonstrate clear boundaries that are in line with the CQRS. DDD is a framework that has an architectural structure characterized by the “layered approach”. As discussed in the previous article, the application layer, domain model layer, and infrastructure layer are integral components of the DDD. These layers play a crucial role in achieving the separation of concerns and effectively controlling the complexity of code. The proposed division of .NET assemblies is shown in figure 5, as indicated by the researched statements.



*Figure 5. DDD organized project structure*

The figure illustrates the architecture of DDD, which showcases a systematic arrangement of different components that contribute to the functional coherence of an order management system. The 'Orders Api' (which represents 'Orders Command Api', 'Orders Query Api' or 'Orders Receiver Api') is situated at the highest level of the hierarchy and plays a crucial. It acts as a central conduit, coordinating the interactions between the 'Business', 'Core', and 'Persistence' layers. The assembly known as 'Core' serves as a central hub for commands, queries, and validation models. This creates a strong foundation for operational logic and data manipulation. Simultaneously, the 'Business' assembly contains the command and query handlers, along with interfaces to the “Event Bus”. This facilitates a smooth exchange of messages and guarantees accurate execution of CQRS. Upon further examination of the structural framework, it becomes evident that the 'Domain' assembly serves as a repository for aggregates, entities, events, and Data Transfer Objects (DTO). The ‚Persistence' assembly plays a role in the overall architectural framework by housing repository classes. These classes serve as a reliable and secure storage for data, ensuring its organized retention and enabling its efficient retrieval and utilization of a cloud database. The test project, as isolated from “source”, has a comprehensive suite of integration tests that have been developed using the Test-Driven Development (TDD) approach.

***3.2. CQRS in Practice***

A regular paper may consist of multiple sections. Title of each section.

***3.3. Ubiquitous Language via Functional Programming***

A regular paper may consist of multiple sections. Title of each section

***3.4. Referencing the Event Sourcing***

A regular paper may consist of multiple sections. Title of each section

***3.5. Integrating a test suite***

A regular paper may consist of multiple sections. Title of each section

1. **Discussion**

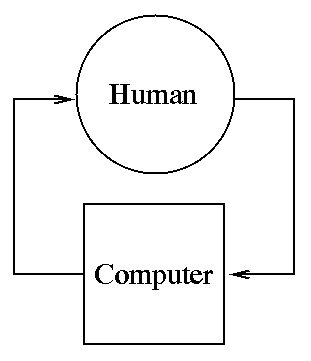
Times New Roman 11 – point font should be used for normal text with “single” line spacing. The manuscript has to be prepared in two columns separated by 5 mm (0.2”). The text should be aligned to both the left and right (justified). The margins for A4 (210×297 mm2) paper are given in Table 1.

*Table 1. Page layout description*

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| Column Spacing | 5 mm | (0.2") |

A regular paper may consist of multiple sections. Title of each section (except references and acknowledgements sections) should be formatted with 11- point font in bold. Spacing between the title and the text should be 11 – point. The use of options “add space before/after paragraph” is not allowed.

Titles (subtitles) of sections can further be divided in subsections, which should use a 10 – point font in italicandbold, following title case capitalization. Figures should be one column wide, centered, and in line with the text (select the table, right click, chose options “wrap text” and then “in line with text”). If it is impossible to place the figure in one column, two column width figures are permissible. It is essential to ensure that all figures maintain a high quality with easily readable labels. Each figure must include a caption placed beneath it while table captions are placed above it. Tables/figures should be inserted in the text after they have been mentioned. When creating captions for figures and tables, use a 10-point italic font without punctuation at the end (e.g., Figure 1).



*Figure 1. Caption of the figure*

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1. Introduction

Indent the first line of each paragraph of text with 0,5 – point from the left margin. For the numeration of subsection titles, use a multilevel list style as illustrated below:

1. Introduction

1.1. Writing Instructions

1.1.1. Subsection: Writing Introductions

Each section should contain a brief introduction. When introducing abbreviations for the first time, provide full form of it, for example: Artificial Intelligence (AI).

well as to enhance credibility of your research. In case your research is quantitative, methodology should present the way numerical data was collected and how mathematical analyses are conducted to observe, analyse, access, and test experiments and hypotheses. Qualitative research involves collection and analysis of non-numerical data (e.g.: text, video, or audio) with the aim of explaining concepts, opinions, perspectives, or personal experiences.

Times New Roman 11 – point font should be used for normal text with “single” line spacing. The manuscript has to be prepared in two columns separated by 5 mm (0.2”). The text should be aligned to both the left and right (justified). The margins for A4 (210×297 mm2) paper are given in Table 1.

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| Column Spacing | 5 mm | (0.2") |

1. **Conclusion**

Be brief and state the most important conclusions from your paper as well as further implications for the field. Discuss benefits or shortcomings of your work and suggest future areas for research. Do not use equations, figures, or references here.

Acknowledgements (If any)

These and the Reference headings are in bold but have no numbers. Titles and text of sections references and acknowledgements should be formatted with 10 – point font, yet text in acknowledgements section should be in italic font. Include the names of the funding agencies or organizations, grant numbers - number of project, and any relevant details about the funding.

**References**

References section is not enumerated. The use of hyperlinks should be avoided as much as possible. When including in-text references, they should be on the same level as the rest of the text e.g.: “References give proper credit to all work included [1]”. For in-text references TEM Journal prefers IEEE style (reference numbers in square brackets “[2], [3]”) in combination with APA style (the use of authors’ names with reference numbers, yet it is better to use only IEEE format as much as is possible). When citing the author's name, use the following format: 'as shown by Brown [4].' In cases where only the reference itself is included, use this format: 'References are of great importance in scientific papers [2]’.When including multiple sources, format them as follows: [1], [2], [3].

When introducing references in the reference list use 10 point font, following the form provided below. Examples of the form:

1. Wong, B., & Kokko, H. (2005). Is science as global as we think?. *Trends in ecology & evolution*, *20*(9), 475-476.
2. Hennessy, J. L., & Patterson, D. A. (2012). *Computer architecture: a quantitative approach*. Elsevier.
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<https://doi.org/10.1073/pnas.0805417105>

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<https://www.festo.com/rep/en_corp/assets/pdf/info_501_en.pdf> [accessed: 19 September 2022].