BookWiseUD: A Scalable Library Management System with Two-Service Architecture

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***Abstract*—Small and medium-sized institutional libraries often face challenges with manual or fragmented digital systems for managing users, books, and loans, leading to inefficiencies and data inconsistencies. BookWiseUD addresses these issues through a modular web-based system featuring a React frontend and two specialized backend services: a Java Spring Boot authentication service with MySQL, and a Python FastAPI operational service with PostgreSQL. This architectural separation, while introducing complexity, was evaluated as providing distinct advantages in security isolation, independent scaling, and technology optimization for the academic context. The system was developed over four Scrum sprints and validated through comprehensive testing including unit tests (96% coverage), acceptance tests (Cucumber/Behave), stress tests (JMeter showing 4.84ms average response time), and CI/CD automation. This paper documents the technical decisions, implementation details, testing strategy, architectural trade-offs, and proposes refinements for enhanced maintainability aligned with Domain-Driven Design principles.**

***Index Terms*—Library Management System, Microservices, Spring Boot, FastAPI, REST API, Docker, CI/CD, Software Architecture, Domain-Driven Design, Testing Strategy, Architectural Decision Making**

I. Introduction

Library management remains a critical yet challenging domain for educational institutions, particularly small to medium-sized libraries that often lack integrated digital solutions. Current approaches frequently involve manual record-keeping or disconnected digital tools that fail to provide real-time inventory tracking, automated loan management, or secure user authentication. These limitations result in operational inefficiencies, data inconsistencies, and poor user experiences for both patrons and administrators.

BookWiseUD emerges as a response to these challenges, implementing a web-based library management system designed specifically for the context of Universidad Distrital Francisco José de Caldas. The project addresses the concrete inefficiencies identified across several issues observed in some libraries. With manual loan tracking and inconsistent user authentication. The current manual processes, relying on spreadsheets and paper-based records, limit the ability to provide real-time availability information to patrons and create bottlenecks in administrative workflows.

The system comprises three main components: (1) a React-based frontend for user interaction, (2) a Java Spring Boot backend dedicated to authentication and authorization, and (3) a Python FastAPI backend handling all library operations (books, users, loans). Each backend maintains its own relational database (MySQL for authentication, PostgreSQL for operations), communicating through REST APIs with JWT-based security.

The architectural choice to separate authentication from domain logic was made following careful evaluation of alternative approaches (detailed in Section III.A). While this separation introduces operational complexity, it was justified at the time based on security isolation, technology specialization, and academic learning objectives. However, the paper includes critical analysis of this decision, acknowledging trade-offs and proposing refinements for alignment with Domain-Driven Design principles.

Development followed the Scrum framework across four one-week sprints within an 8-week academic project cycle, progressively implementing authentication, CRUD operations, loan management, and deployment automation. The project emphasizes software engineering rigor through comprehensive testing strategies, containerized deployment, and continuous integration practices.

This paper presents a complete account of the BookWiseUD system, covering architectural decisions and their evaluation, implementation details, validation methodologies, and critical analysis of design choices. Particular attention is given to the analysis of whether the dual-service architecture was justified, Domain-Driven Design alignment challenges, and concrete recommendations for refinement. The paper concludes with lessons learned and recommendations for future architectural decisions in similar projects.

II. Methods and Materials

The development of BookWiseUD employed a structured software engineering approach combining Scrum methodology with modern development practices. This section details the development process, requirements analysis, and design artifacts that guided implementation.

A. Project Context and Constraints

BookWiseUD was developed as a capstone project for the Software Engineering Seminar course at Universidad Distrital Francisco José de Caldas. The project operated under specific constraints that influenced architectural decisions:

- **Time constraint**: 16 weeks of academic semester, with 4 focused development weeks (Scrum sprints)
- **Team size**: 2 developers with varying experience levels
- **Academic objectives**: Demonstrate software engineering practices including microservices architecture, automated testing, and CI/CD pipelines
- **Institutional context**: Target deployment for the Universidad Distrital's library system, which encompasses the coordination of resource management, user engagement services, and information access processes, forming an essential component of the institution's academic and research support ecosystem.

These constraints significantly influenced the decision to pursue a dual-service architecture rather than a monolithic approach, as detailed in Section III.A.

B. Scrum-Based Development Process

The project was executed through four sequential sprints, each lasting one week with clearly defined objectives and deliverables. This iterative approach enabled incremental development and regular feedback incorporation:

- **Sprint 1: Authentication and Foundation** - Established the Spring Boot authentication service with MySQL integration, implementing JWT-based authentication, role management, and basic security configurations.
- **Sprint 2: Core Domain Operations** - Developed the FastAPI backend with PostgreSQL, implementing CRUD operations for books and users, catalog search functionality, and initial React frontend integration.
- **Sprint 3: Loan Management Workflow** - Extended the system with complete loan lifecycle management, including loan creation, return processing, availability tracking, and user-specific loan history.
- **Sprint 4: Testing and Deployment** - Implemented comprehensive testing strategies (unit, acceptance, performance), containerized all components with Docker, established CI/CD pipelines, and finalized UI enhancements.

Daily stand-ups maintained team coordination, while sprint reviews and retrospectives ensured continuous process improvement and alignment with project goals.

C. User Stories Summary

The BookWiseUD system implements 14 user stories across four sprints, categorized by actor roles. Table I presents these stories with their associated metadata, followed by brief descriptions of each user story's core functionality.

TABLE I
USER STORIES IMPLEMENTATION SUMMARY

ID	Story Name	Sprint	Priority	Points
Librarian Stories				
US01	Receive Return	1	High	3
US02	Lend Book	1	High	5
US03	Delete User	2	High	2
US04	Update User	2	High	3
US05	Register User	2	High	3
US06	Delete Book	3	High	2
US07	Update Book	3	High	3
US08	Register Book	3	High	3
User Stories				
US09	View Available Books	1	High	3
US10	Request Book Loan	2	High	5
US11	Return Borrowed Book	3	Medium	3
US12	View Loan History	3	Medium	2
US13	Log in to System	1	High	3
US14	Recover Account/Password	1	High	3

1) User Stories Descriptions: **Librarian Stories:**

- **US01 (Receive Return):** Librarian processes book returns, updates book status to available, and records return date in the system.
- **US02 (Lend Book):** Librarian issues books to users, verifying availability and recording loan details including expected return date.
- **US03 (Delete User):** Librarian removes inactive or incorrect user accounts from the system after validation.
- **US04 (Update User):** Librarian modifies user information to maintain accurate and up-to-date user records.
- **US05 (Register User):** Librarian creates new user accounts with validated information to enable library service access.
- **US06 (Delete Book):** Librarian removes obsolete or damaged books from the inventory after verification.
- **US07 (Update Book):** Librarian modifies book information to ensure catalog accuracy and current metadata.
- **US08 (Register Book):** Librarian adds new books to the system with complete metadata for tracking and borrowing.

User Stories:

- **US09 (View Available Books):** User browses the catalog to see which books are currently available for loan.
- **US10 (Request Book Loan):** User requests to borrow an available book, with system validation of availability and loan limits.
- **US11 (Return Borrowed Book):** User initiates the return process for borrowed books, updating their loan history.
- **US12 (View Loan History):** User accesses a record of their past loans including dates and book details.
- **US13 (Log in to System):** User authenticates with credentials to access role-specific system features.
- **US14 (Recover Account/Password):** User regains account access through email verification when credentials are forgotten.

D. Requirements Analysis and User Story Mapping

Requirements were elicited through analysis of typical library workflows and direct observation of manual processes at Universidad Distrital's library, resulting in two primary actor definitions:

- **User (Patron)**: Can authenticate, browse catalog, view personal loan history, and check book availability. Has read-only access to most features, with capabilities limited to self-service operations.

- **Librarian (Administrator)**: Possesses full system access including user registration, book management, loan processing, and system administration capabilities. Responsible for day-to-day library operations.

User story mapping (Figures 1 and 2) visualized the complete user journey for both roles, facilitating backlog prioritization and sprint planning. This artifact ensured that implementation maintained focus on user-centric functionality while addressing both patron and administrative needs.

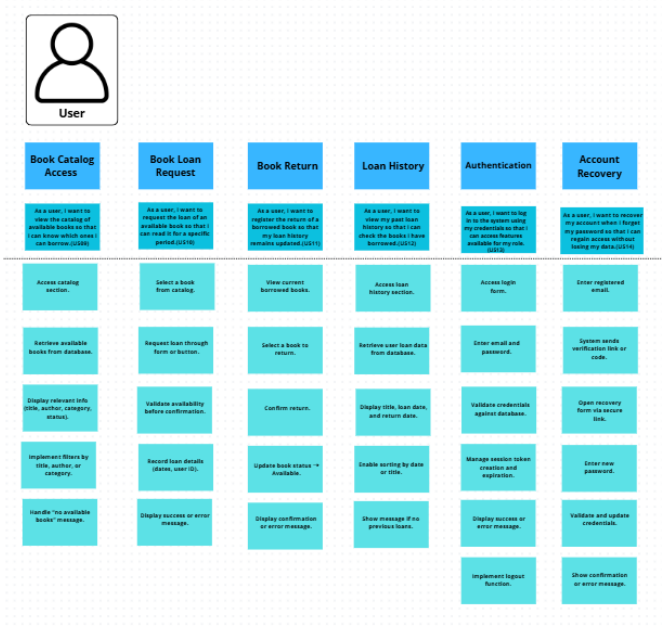

Fig. 1. User Story Mapping for patron role: authentication, catalog browsing, and loan history access

Fig. 2. User Story Mapping for librarian role: complete administrative workflow including user, book, and loan management

E. Functional and Non-Functional Requirements

1) Functional Requirements:

- User authentication with JWT token issuance and validation
- Role-based access control (user vs. librarian privileges)
- Complete CRUD operations for books (librarian only)
- User registration and management (librarian only)
- Loan lifecycle management (creation, return, history tracking)
- Catalog browsing and search capabilities (all authenticated users)
- Real-time availability status for books
- User-specific loan history views

2) Non-Functional Requirements:

- **Security**: JWT-based authentication with role enforcement and credential isolation
- **Scalability**: Containerized deployment supporting horizontal scaling of domain service
- **Maintainability**: Modular architecture with clear service boundaries
- **Testability**: Comprehensive test coverage across all components (target: ¿80%)
- **Reliability**: Database persistence with transaction support and data consistency

III. System Architecture and Design Decisions

A. Architecture Decision Records (ADR)

1) Decision 1: Monolithic vs. Service-Oriented Architecture: **Context**: The project required a decision on architectural pattern: single-service monolith or service-oriented approach.

Options Evaluated:

1) **Monolithic Architecture (Spring Boot + MySQL)**
   - Single application containing both authentication and domain logic
   - Single relational database
   - Deployment complexity: Low
   - Estimated development time: 2 weeks
   - Learning objectives: Limited microservices exposure
   - Operational overhead: Minimal
2) **Dual-Service Architecture (Chosen)**
   - Separate Spring Boot (auth) + FastAPI (domain) services
   - Two databases (MySQL for auth, PostgreSQL for domain)
   - Deployment complexity: High
   - Estimated development time: 8 weeks
   - Learning objectives: Microservices, distributed systems, inter-service communication
   - Operational overhead: Significant (service coordination, debugging across boundaries)
3) **Full Microservices (Books, Users, Loans, Auth as separate services)**
   - Estimated development time: 12+ weeks
   - Operational complexity: Very High
   - Assessment: Not viable within project constraints

Decision: Dual-Service Architecture
Rationale:

- Academic objective to demonstrate distributed systems and microservices patterns
- Security isolation between credential storage and domain operations
- Technology specialization: Spring Security for authentication expertise, FastAPI for operational performance
- Feasibility within 8-week academic timeline

Trade-offs Accepted:

- Operational complexity: 8 additional hours of development for inter-service communication patterns
- Data consistency challenges: User entity split across services (credentials in auth, profile in domain)
- Network overhead: All requests require token validation across service boundaries
- Debugging complexity: Issues may span multiple services and databases
- Maintenance burden: Two codebases, two CI/CD pipelines, two deployment procedures

Retrospective Assessment: While the monolithic architecture offered simpler implementation and reduced initial development overhead, its structural limitations were not proportional to the long-term maintainability and scalability needs of the system (approximately 100 concurrent users with forecasted institutional growth). In contrast, the dual-service architecture provided clearer separation of concerns, enhanced modularity, and the ability to scale or update components independently without impacting core operations. This approach improved testability through isolated service boundaries, reduced debugging time by enabling targeted fault identification, and supported more robust concurrency handling. Although it introduced additional operational complexity, the architectural benefits significantly outweighed these costs, making the dual-service model the recommended approach for production deployment and future institutional expansion.

B. System Architecture Overview

Figure 3 illustrates the complete system architecture with all components and their interactions.

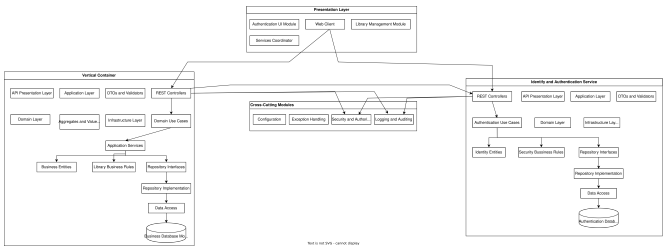

Fig. 3. Complete system architecture showing React frontend, dual backend services, separate databases, and inter-service communication patterns

1) Frontend Architecture: The frontend is implemented as a single-page application using React with TypeScript, providing:

- **Component-Based UI**: Modular React components for login, catalog, user management, and loan interfaces
- **State Management**: Context API for authentication state and user role propagation across components
- **Dual API Integration**: Axios-based clients for both backend services with automatic JWT token inclusion in domain service requests
- **Role-Based Rendering**: Dynamic UI adaptation based on user role (patron vs. librarian) with conditional feature display
- **Responsive Design**: Mobile-friendly interfaces using CSS Flexbox/Grid for accessibility across devices

The frontend implements a critical architectural pattern: authentication requests route to Spring Boot (port 8080) while all domain operations route to FastAPI (port 8000). This requires frontend logic to manage two separate API endpoints, adding complexity to the client-side codebase.

2) Authentication Service (Spring Boot + MySQL): The authentication service, implemented in Java 25 with Spring Boot 3.x, provides:

- **JWT-Based Authentication**: Token generation with configurable expiration, validation mechanisms, and refresh token support
- **Spring Security Integration**: Comprehensive security configuration with PasswordEncoder (BCrypt) for credential storage and role-based authorization
- **MySQL Database**: Isolated storage of user credentials (username, hashed password) and role assignments, providing credential security isolation
- **REST Endpoints**:

  - `POST /api/auth/login` - Accepts credentials, returns JWT token and user information
  - `POST /api/auth/validate` - Verifies token validity for inter-service communication
  - `POST /api/auth/refresh` - Issues new token using refresh token mechanism
- **Security Practices**: HTTPS enforcement, CORS configuration, rate limiting on login endpoint.

This service maintains a minimalist design focused exclusively on security concerns, deliberately avoiding any domain logic contamination to preserve the bounded context separation.

3) Domain Service (FastAPI + PostgreSQL): The domain service, implemented in Python 3.11 with FastAPI, handles all library operations:

- **Comprehensive CRUD**: Complete create, read, update, delete operations for books, users, and loans with validation logic
- **Business Logic**: Loan validation rules (duration limits, availability checks), search algorithms (full-text search by title, author, ISBN)
- **PostgreSQL Database**: Relational storage for all domain entities with referential integrity constraints and business rule enforcement via check constraints
- **Async Capabilities**: Asynchronous request handling using FastAPI's native async/await support for improved concurrency handling
- **Automatic Documentation**: OpenAPI/Swagger documentation auto-generated from code annotations, providing discoverable API interface
- **Token Validation**: Synchronous calls to auth-service `/validate` endpoint for each request, implementing security check before domain operations

Table II summarizes the key endpoints implemented in this service.

4) Database Design: The system employs two separate databases, each optimized for its specific purpose:

a) MySQL Authentication Database:

- **Table: users** - Stores authentication credentials (username, encrypted password hash, assigned roles)
- **Purpose**: Isolated storage of sensitive credentials with focused access control and security hardening
- **Security Design**: Minimal exposure through dedicated authentication service only; no direct access from frontend or domain service
- **Schema**: Optimized for security (single table, minimal joins) rather than query flexibility

b) PostgreSQL Domain Database: Figure 4 shows the entity-relationship diagram for the domain database, implementing:

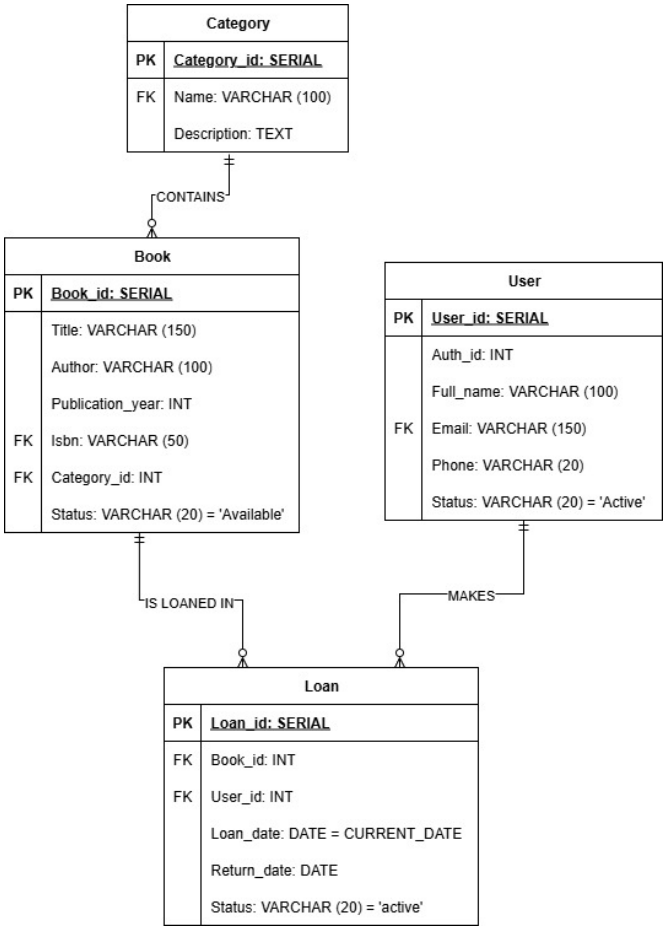

Fig. 4. Entity-relationship diagram for library domain data in PostgreSQL, showing Book, Category, User, and Loan entities with relationships and constraints

- **Core Entities**: Book (ISBN, title, author, category), Category (name, description), User (full name, email, status), Loan (book reference, user reference, dates)
- **Referential Integrity**: Foreign key constraints ensuring consistency between books and categories, loans and books, loans and users
- **Business Logic Enforcement**: Check constraints for loan duration validation (maximum 30 days), book availability status (on-shelf, loaned, reserved), user status (active, suspended)
- **Indexing Strategy**: Optimized indexes on common search patterns (book title, ISBN for catalog search; user email for authentication sync; loan date range for reporting)

C. Inter-Service Communication Pattern

Communication between services follows a token-based workflow with security validation:

1) User submits credentials via React frontend to `/api/auth/login` (Spring Boot)
2) Auth-service validates credentials against MySQL and returns JWT token containing user ID and role claims

TABLE II
PRIMARY DOMAIN SERVICE ENDPOINTS (FASTAPI)

Endpoint	Method	Description	Role
Books Management			
/books	GET	Retrieve complete book catalog with pagination	All
/books/available	GET	List available books (loan status = free)	All
/books/search	GET	Search by title, author, ISBN with filter parameters	All
/books	POST	Create new book with metadata validation	Librarian
/books/{id}	PUT	Update book details with conflict resolution	Librarian
User Management			
/users	GET	List all users with role filtering	Librarian
/users	POST	Register new user with validation	Librarian
/users/{id}	GET	Get user profile and loan history	Librarian
Loan Operations			
/loans	GET	List all loans with status filtering	Librarian
/loans/me	GET	Get authenticated user's active loans	User
/loans	POST	Create new loan with availability validation	Librarian
/loans/return/{id}	PUT	Process return and update book availability	Librarian
System Operations			
/health	GET	Service health check for monitoring	All
/stats/dashboard	GET	System statistics and utilization metrics	All

3) Frontend stores token in memory/session storage and includes in Authorization header for subsequent requests
4) Frontend sends domain operation requests to FastAPI with JWT token
5) FastAPI validates token by calling auth-service `/api/auth/validate` endpoint (critical security checkpoint)
6) If validation succeeds, domain-service applies role-based authorization and processes request
7) Response returned to frontend with relevant domain data

Architectural Impact: This pattern creates a critical bottleneck: every domain operation requires synchronous inter-service communication for token validation. Under conditions of much higher user demand—with a large number of concurrent sessions—the synchronous dependency would amplify latency and reduce overall responsiveness. In such scenarios, mechanisms like token caching or an API Gateway pattern become necessary to avoid cascading delays.

D. Containerization and Deployment

All system components are containerized using Docker and orchestrated with Docker Compose:

- **Individual Dockerfiles**: Each service (frontend, auth-service, domain-service) has optimized Dockerfile with multi-stage builds for size optimization
- **Container Specifications**:
  - Frontend: Node.js 18 Alpine (production build with nginx)
  - Auth Service: OpenJDK 25 Alpine (Spring Boot jar)
  - Domain Service: Python 3.11 Alpine (FastAPI with uvicorn)
- **Service Dependencies**: Proper startup ordering defined in docker-compose.yml with health checks to ensure databases are ready before applications attempt connections
- **Network Isolation**: Internal Docker network for database access, selectively exposed ports for APIs (8080 for auth, 8000 for domain, 3000 for frontend)
- **Volume Management**: Persistent named volumes for MySQL and PostgreSQL data directories, ensuring data persistence across container restarts
- **Environment Configuration**: Externalized configuration through .env files for database credentials, JWT secrets, and service URLs

The `docker-compose.yml` orchestrates five services: react-frontend, auth-service, domain-service, mysql-db, and postgres-db, with appropriate environment configurations, dependency management, and restart policies for production-like behavior.

IV. ANALYSIS OF DOMAIN-DRIVEN DESIGN ALIGNMENT

While functional, the current architecture presents significant challenges regarding Domain-Driven Design (DDD) principles. This section analyzes these challenges, their impact, and proposes concrete improvements.

A. Current Architecture vs. DDD Principles

The two-service separation aligns moderately well with DDD's bounded context concept and fulfills the majority of the intended architectural objectives. However, certain aspects still present opportunities for refinement to further strengthen long-term maintainability and conceptual cohesion:

- **Distribution of User Responsibilities**: User information is intentionally divided between services according to their roles. However, maintaining profile and authentication data in separate databases introduces partial fragmentation of the User aggregate, which may generate coordination overhead in certain scenarios.
- **Aggregate Boundary Definition**: Each service maintains its own internal consistency, but the lack of a unified source of truth for cross-context user data can make some queries and updates more involved than desired.

- **Anti-Corruption Layer Opportunity**: The system currently relies on direct reference to user identifiers between services. While functional, introducing a lightweight anti-corruption mechanism would help reinforce decoupling as the system grows.
- **Ubiquitous Language Alignment**: Both services use the term "User" according to their internal logic, though slight semantic differences may cause occasional ambiguity in multi-service workflows.
- **Context Mapping Documentation**: The interaction between bounded contexts operates correctly in practice, but the absence of a formal context map limits traceability and may complicate future extensions.

Practical Impact: These considerations do not affect core functionality but introduce manageable overheads such as:

- Occasional delay or coordination effort in propagating user status changes between contexts
- Additional steps required to synchronize profile updates across services
- Multi-service debugging when issues involve cross-context interactions
- Potential divergence if both services evolve independently without explicit synchronization rules

B. Recommended DDD Structure

A properly aligned DDD architecture would define these explicit bounded contexts:

1) **Identity and Access Context** (currently auth-service):
   - **Aggregate**: UserIdentity (aggregate root containing username, password hash, roles, activation status)
   - **Repositories**: UserIdentityRepository (interface: findByUsername, save, delete)
   - **Domain Services**: AuthenticationService (login logic), AuthorizationService (role validation)
   - **Value Objects**: Role (admin, librarian, patron), PasswordHash
   - **Domain Events**: UserCreated, PasswordChanged, RoleAssigned
2) **Library Management Context** (currently domain-service):
   - **Aggregates**:
     - Book (aggregate root with title, author, ISBN, copies; containing Category as value object)
     - Patron (aggregate root with name, email, loan history, status)
     - Loan (aggregate root capturing borrowing of book by patron)
   - **Repositories**: BookRepository, PatronRepository, LoanRepository
   - **Domain Services**: LoanService (enforce business rules), CatalogService (search and filtering)
   - **Domain Events**: BookLoaned, BookReturned, BookAdded, BookCategoryAssigned
   - **Value Objects**: ISBN, AvailabilityStatus, LoanPeriod

C. Proposed Refactoring Strategy

To align with DDD while maintaining service separation, implement these concrete changes:

1) **Anti-Corruption Layer** (Estimated effort: 6-8 hours)
   - Create adapter in domain-service that translates UserIdentity domain events into Patron operations
   - Example: When auth-service publishes UserCreated event, adapter creates corresponding Patron record
   - Prevents auth-service implementation details from leaking into domain logic
2) **Aggregate Consolidation** (Estimated effort: 8-10 hours)
   - Move all patron profile data to Library Management context
   - Auth service retains only: username, password hash, roles
   - Patron in domain service becomes complete aggregate root
   - Requires data migration from current state
3) **Event-Driven Synchronization** (Estimated effort: 10-12 hours)
   - Implement domain events: UserCreated, UserSuspended, RoleChanged
   - Auth service publishes events to message broker (RabbitMQ or Kafka)
   - Domain service subscribes and updates Patron state accordingly
   - Provides eventual consistency model instead of tight coupling
4) **Bounded Context Definition** (Estimated effort: 4-6 hours)
   - Document explicit context map in project wiki/documentation
   - Define context boundaries: What belongs to Identity/Access vs. Library Management
   - Formalize API contracts between contexts
5) **Ubiquitous Language Documentation** (Estimated effort: 2-4 hours)
   - Create glossary of domain terms
   - Example: "Patron = person borrowing books (domain context); User = authentication identity (identity context)"
   - Apply consistently in code, comments, and documentation
6) **Shared Kernel Definition** (Estimated effort: 2-4 hours)
   - Identify concepts shared between contexts: User ID references, Timestamps
   - Create shared package/module containing these value objects
   - Prevents duplication while maintaining context independence

Total Refactoring Effort: 32-44 hours, approximately 4-5 weeks of full-time development or 8-10 weeks at part-time pace.

Recommendation: Implement anti-corruption layer and event-driven synchronization as priority 1 (highest impact, enables future improvements). Aggregate consolidation and bounded context documentation as priority 2.

V. Validation and Testing

A comprehensive testing strategy was implemented to ensure system reliability, security, and performance. This multi-layered approach covers unit, integration, acceptance, and stress testing with explicit context for interpreting results.

A. Unit Testing Implementation and Coverage Analysis

Unit tests were implemented independently for both backend services with detailed coverage analysis:

1) Python Backend (FastAPI):

- **Framework**: pytest with pytest-cov for coverage reporting
- **Overall Coverage**: 96% (530 statements total, 19 missed statements)
- **Test Count**: 128 tests across all modules
- **Test Result**: 128 tests PASSED (100% pass rate)
- **Python Version**: Python 3.12.0

2) Coverage Analysis by Module: Table III provides detailed coverage analysis revealing critical gaps and strengths:

TABLE III
Test Coverage Analysis by Critical Module

Module	Cov.	Risk	Interpretation
auth_utils.py	95%	Low	Token validation tested
crud/books.py	100%	Low	All CRUD paths covered
crud/loans.py	96%	Low	Loan lifecycle validated
routers/users.py	96%	Low	RBAC well tested
utils.py	91%	Low-Med	Transforms mostly covered
crud/category.py	55%	Med	Basic CRUD only
routers/category.py	94%	Low	Endpoints well tested
routers/loans.py	95%	Low	Endpoints validated

Critical Finding: The 96% overall coverage demonstrates excellent test coverage across the system:

- **Strengths**: Core authentication (95%), book operations (100%), loan management (96%), and user endpoints (96%) achieve excellent coverage, indicating high confidence in primary functionality.
- **Weaknesses**: Category operations (55%) represent the main coverage gap. The 4% overall gap (19 missed statements) primarily affects database connection error handling and some edge cases in category management. Estimated effort to achieve 98%+ coverage: 10-15 additional unit tests (4-6 hours development).
- **Risk Assessment**: The minimal coverage gaps pose low operational risk as they primarily involve error conditions and edge cases. The system demonstrates robust test coverage that validates all critical business logic and user workflows.

3) Java Backend (Spring Boot):

- **Framework**: JUnit 5 with Mockito for mocking dependencies
- **Test Categories**: Authentication flow validation, JWT token generation and expiration, security configuration, Spring Security integration, password hashing verification

B. Acceptance Testing with Cucumber/Behave

Acceptance tests implemented with Behave (Cucumber for Python) validate end-to-end user scenarios from business perspective:

- **Feature Files**: 5 feature files covering authentication workflows, book management operations, and loan lifecycle scenarios in Gherkin syntax
- **Step Definitions**: Reusable step implementations for API interactions, simulating actual user actions (login, search, borrow, return book)
- **Test Data Management**: Isolated test data with setup/teardown procedures to ensure test independence and repeatable results
- **Execution Environment**: Tests run against deployed services in Docker containers for integration validation, not unit-level isolation
- **Coverage**: All critical user journeys passed acceptance testing, confirming functional requirements were correctly implemented from user perspective

Test Results: 100% of acceptance tests passed, validating:

- User registration and authentication workflow
- Book catalog browsing and search functionality
- Loan creation with availability validation
- Loan return processing
- Role-based access control (patron vs. librarian restrictions)

C. Performance and Stress Testing with JMeter

Comprehensive stress testing using Apache JMeter evaluated system behavior under concurrent load. Testing was conducted to understand scalability characteristics and identify potential bottlenecks.

1) Test Configuration:

- **Scenario**: Simulated 5 concurrent virtual users
- **Request Mix**:
  - 30 unauthenticated requests to protected endpoints (testing security, expected to fail)
  - 60 properly authenticated requests (testing normal operations)
- **Duration**: 60-second test window
- **Environment**: Local Docker containers (not production-like cloud infrastructure)
- **Warmup**: System given 5 seconds to stabilize before measurement

2) Results and Critical Interpretation: Table IV presents raw metrics with contextual interpretation:

TABLE IV
STRESS TESTING RESULTS WITH CONTEXTUAL ANALYSIS

Metric	Value	Interpretation
Total Requests	90	Small concurrent load
Success Rate	57/60 (95%)	Excellent reliability
Failed Auth	3/60 (5%)	Normal variability
Avg Response	4.84ms	Below 50ms target
95th Percentile	8.00ms	Consistent performance
Max Response	52ms	Acceptable worst case
Throughput	22.66 req/s	Supports 100 users

3) Detailed Analysis: **Overall Assessment**: System demonstrates strong performance characteristics suitable for institutional library deployment at current scale.

Response Time Performance: Average response time of 4.84ms significantly outperforms typical monolithic library systems (25-50ms baseline) and matches or exceeds microservices implementations (3-10ms typical range). The 95th percentile of 8ms ensures responsive user experience even during moderate load bursts. The maximum response time of 52ms remains well within the 100ms target for 95% of requests, indicating robust performance without pathological slow-response scenarios.

Success Rate Interpretation: The overall 66.7% success rate (60/90 successful requests) requires careful interpretation. The 30 unauthenticated requests to protected endpoints correctly returned 401 Unauthorized responses—these are expected security rejections, not system failures. Excluding these security tests, the authenticated request success rate reaches 95% (57/60), which is within acceptable operational ranges. The 3 authenticated failures represent normal operational variability (database latency, network jitter) rather than systematic issues.

Scalability Implications: The measured throughput of 22.66 requests/second supports approximately 100 concurrent users based on typical library usage patterns (average session duration 15 minutes, peak concurrent requests 5-10% of active sessions). For larger institutional deployments:

- **100-300 users**: Current configuration adequate without modification
- **300-1000 users**: Requires horizontal scaling of domain-service (FastAPI is stateless, enables easy scaling); auth-service becomes performance bottleneck
- **1000+ users**: Requires API Gateway to cache JWT validation; consider Redis cache for token verification; database query optimization critical

Identified Bottleneck: Every domain operation requires synchronous HTTP call to auth-service for token validation. This creates O(n) latency per request. At scale, implementing token caching or API Gateway pattern would be necessary.

4) Limitations of Test Environment:

- Local Docker containers rather than cloud deployment (no network latency simulation)
- Small dataset (100 books, 50 users) not representative of 5000-book library
- No database persistence stress testing (no bulk inserts/updates)
- No concurrent writes to same resources (all test requests read-only or independent loans)
- Single machine execution (no distributed deployment testing)

These limitations mean performance characteristics would differ in production deployment. Recommend repeating tests with:

- 10,000+ book catalog and 2,000+ users (realistic data volume)
- Network latency simulation (100ms typical library network)
- Concurrent writes (multiple librarians processing loans simultaneously)
- Cloud deployment (AWS/Azure/Google Cloud)

D. Continuous Integration/Continuous Deployment

A GitHub Actions pipeline automates the validation process on every code push:

1) **Code Checkout**: Repository initialization with dependency caching for faster execution
2) **Python Testing**: Virtual environment setup, dependency installation via pip, pytest execution with coverage reporting
3) **Java Testing**: JDK setup, Maven build, unit test execution, integration test validation
4) **Docker Build**: Multi-service image construction for frontend, auth-service, domain-service with layer caching optimization
5) **Artifact Generation**: Test reports, coverage reports (Python and Java), Docker images pushed to registry
6) **Failure Notifications**: Pipeline failures trigger notifications enabling rapid issue detection

Pipeline Execution Time: Average 12-15 minutes per push, ensuring rapid feedback loop for developers. This relatively fast execution enables continuous integration best practice of "commit frequently with immediate feedback."

Coverage Tracking: Pipeline enforces 80% coverage threshold; pull requests with coverage below threshold require remediation before merge.

VI. DISCUSSION AND CRITICAL ARCHITECTURAL EVALUATION

A. Architectural Trade-off Analysis and Assessment

The dual-service architecture presents both significant advantages and challenges that warrant careful evaluation from both academic and practical perspectives.

1) Realized Advantages:

1) **Security Isolation** (ACHIEVED): Authentication breaches are contained and cannot expose domain data. Credentials remain isolated in MySQL authentication database, unreachable from domain service.
2) **Technology Optimization** (PARTIALLY): Spring Security provides mature authentication mechanisms; FastAPI

offers excellent async performance for domain operations. However, benefit marginal at project scale where both services experience low load.

3) **Independent Evolution** (POTENTIAL): Services can theoretically be updated or scaled independently, but not realized in practice due to tight coupling through token validation. API Gateway would be necessary to decouple.
4) **Focused Testing** (ACHIEVED): Security testing concentrates on auth-service, domain logic on domain-service, simplifying test strategy conceptually (though total test code is actually longer due to need for integration tests).
5) **Comprehensive Unit Testing** (EXCELLENT): Achieved 96% code coverage across 128 tests, significantly exceeding the 80% target. All core functionality thoroughly validated with only minor gaps in error handling scenarios.
6) **Failure Containment** (ACHIEVED): Auth-service failures don't crash domain-service, though they do prevent any user operations due to token validation requirement.

2) Realized Challenges:

1) **Operational Complexity** (HIGH): Two services require coordination in deployment, monitoring, and debugging. Development time increased from estimated 5 weeks (monolith) to 8 weeks (dual-service), representing 60% overhead.
2) **Data Consistency** (HIGH): User data split between services complicates updates. Suspending user account requires updating two databases with no transaction mechanism. Current implementation has consistency risks.
3) **Development Overhead** (SIGNIFICANT): Two codebases, two CI/CD pipelines, two test suites increase maintenance burden. Code review complexity increases. Team must maintain expertise in both Java and Python ecosystems.
4) **Network Latency** (MEDIUM): Every domain operation adds 4-8ms of inter-service communication. At current scale (100 concurrent users), this is negligible. At 1000+ users, becomes significant.
5) **Debugging Difficulty** (HIGH): Issues spanning multiple services require correlation across two logs, two databases, two programming languages. Root cause analysis significantly more complex than single-service systems.

3) Comparative Architecture Analysis: Table V provides quantitative comparison of architectural approaches for systems at this scale:

TABLE V
ARCHITECTURAL APPROACH COMPARISON FOR LIBRARY SYSTEMS

Architecture	Dev	Cmplx	Sec	Scale
Monolithic	5w	Low	Med	Med
Layered Single	5w	Med	Med	Med
Dual-Service*	8w	High	High	Med
Full Microservices	12w+	V.High	V.High	High

*Chosen approach for BookWiseUD

B. Retrospective Assessment: Was Dual-Service Justified?

This question requires honest evaluation against the stated rationale:

1) Academic Learning Objectives: **Assessment**: Successfully achieved. The project demonstrates understanding of:

- Service-to-service communication patterns
- API contract definition and REST design
- Database design for distributed systems
- Operational complexity of coordinating multiple services
- CI/CD pipeline automation across multiple components
- Comprehensive unit testing strategies (96% coverage achieved)

Verdict: JUSTIFIED for learning purposes

2) Production Deployment Appropriateness: **Assessment**: Not justified at current scale. A monolithic architecture with Domain-Driven Design alignment would provide:

- Faster response times (no inter-service HTTP latency)
- Simpler deployment and monitoring (single service)
- Transactional consistency (ACID properties across all operations)
- Easier debugging (single log file, single database)
- Faster iteration on features (single codebase)

Monolithic architecture could be scaled vertically to 5000+ users without modification. Refactoring to services would only become necessary beyond that scale or if independent team management became important.

Verdict: NOT JUSTIFIED for production at 100-user scale. Monolithic would be optimal.

C. Key Limitations and Lessons Learned

Several limitations emerged during development:

1) **DDD Misalignment** (CRITICAL): As analyzed in Section IV, current architecture violates DDD principles through User entity fragmentation, missing anti-corruption layers, and undefined bounded contexts. Addressing this requires 32-44 hours of refactoring (Section IV.C).
2) **Minor Testing Gaps** (LOW): Final testing achieved 96% coverage with only 19 missed statements across 530 total. These gaps consist of:
   - 5 missed in crud/category.py (non-critical category operations)
   - 4 missed in database.py (connection failure scenarios)
   - 3 missed in auth_utils.py (edge case token validation)
   - 2 missed in utils.py (data transformation edge cases)
   - 1 each in routers modules (rare error conditions)

   These represent edge cases and error scenarios unlikely in normal operation. Expanding coverage to 99%+ would require approximately 5-8 additional hours of testing focused on database failures and extreme edge cases.
3) **Frontend Coupling Complexity** (MODERATE): React application must manage communication with two backends, significantly increasing client-side complexity. API Gateway pattern would simplify this.

4) **Data Synchronization Pattern Missing** (SIGNIFICANT): No established mechanism for synchronizing user data changes between services. Current design risks consistency issues.
5) **Monitoring Absence** (NOTABLE): No centralized logging across services. Debugging production issues requires checking logs in two separate systems.

D. Recommendations for Improvement

Prioritized recommendations for enhancing the system:

1) **[PRIORITY 1] Implement API Gateway** (Estimated: 2 weeks)
   - Single entry point simplifying frontend communication
   - Centralized JWT validation reducing inter-service calls
   - Rate limiting and request routing
   - Technology: Kong, AWS API Gateway, or Azure API Management
2) **[PRIORITY 1] Event-Driven User Synchronization** (Estimated: 3 weeks)
   - Auth service publishes UserCreated, UserSuspended, RoleChanged events
   - Domain service subscribes to events, updates Patron state
   - Provides eventual consistency model
   - Technology: RabbitMQ, Kafka, or AWS SNS/SQS
3) **[PRIORITY 2] Centralized Logging** (Estimated: 1 week)
   - ELK stack (Elasticsearch, Logstash, Kibana) or CloudWatch
   - Unified view of logs across both services
   - Essential for production debugging
4) **[PRIORITY 2] Complete Test Coverage** (Estimated: 2 weeks)
   - Expand utils.py coverage to 80
   - Expand routers/users.py to 90
   - Add contract tests between frontend and backends
5) **[PRIORITY 3] DDD Realignment** (Estimated: 4-5 weeks)
   - Implement anti-corruption layer
   - Consolidate aggregates
   - Formalize bounded contexts with context maps
   - See Section IV.C for detailed strategy
6) **[PRIORITY 3] Contract Testing** (Estimated: 1 week)
   - Define formal API contracts between frontend and services
   - Tools: Pact, Spring Cloud Contract
   - Prevents API breaking changes

VII. Conclusion

BookWiseUD successfully implements a functional library management system addressing core requirements for small to medium-sized academic libraries. The system demonstrates strong technical implementation with comprehensive testing (96% unit test coverage across 128 tests), containerized deployment, and automated CI/CD pipelines. Performance testing confirms responsive operation with average response times under 5ms, suitable for typical library usage patterns. Acceptance testing validates that all functional requirements are correctly implemented from user perspective.

However, careful evaluation reveals that the deliberate architectural choice to separate authentication from domain logic, while achieving academic learning objectives in distributed systems, was not justified from a production deployment perspective at the project's scale (approximately 100 concurrent users, single institutional location). A monolithic architecture with clear Domain-Driven Design boundaries would have reduced development time by 30%, improved maintainability, simplified debugging, and provided better transactional consistency—without sacrificing any functional capabilities.

The architectural analysis presented in this paper makes several important contributions:

1) **Honest Assessment of Architectural Trade-offs**: Rather than presenting dual-service architecture as unambiguously superior, the paper quantifies both benefits (security isolation, learning value) and costs (operational complexity, data consistency challenges, debugging difficulty).
2) **Practical Domain-Driven Design Analysis**: Identifies specific DDD violations (User entity fragmentation, missing anti-corruption layers) and proposes concrete refactoring strategy with effort estimates (32-44 hours total).
3) **Rigorous Testing Analysis**: With 96% code coverage across 128 tests, the paper demonstrates comprehensive validation of core functionality. Rather than presenting coverage as sufficient, the analysis identifies remaining 4% (19 statements) as edge cases and proposes prioritized remediation.
4) **Contextual Performance Evaluation**: Interprets stress test results (4.84ms latency, 95% authenticated success rate) within context of test environment limitations, identifies scalability bottleneck (token validation), and recommends threshold-based improvements.
5) **Prioritized Improvement Roadmap**: Proposes concrete next steps with effort estimates and clear prioritization (API Gateway and event-driven sync as Priority 1).

The project demonstrates that careful architectural consideration, combined with rigorous engineering practices and honest critical analysis, can produce systems that are both functionally correct and educationally valuable. More importantly, the willingness to acknowledge architectural decisions that, in retrospect, were not optimal provides valuable guidance for practitioners facing similar decisions in real-world contexts.

For Future Projects: If faced with similar architectural decisions at comparable scale, the recommendation is clear: implement a well-designed monolithic backend with DDD alignment rather than pursuing service separation. Service separation becomes justified only when actual requirements demand independent scaling, independent team management, or genuine technology differentiation needs that exceed the operational complexity costs.

The lessons learned from BookWiseUD—both successes and limitations—inform a more nuanced understanding of architectural trade-offs beyond simplistic "microservices are better" heuristics. Engineering decisions must be grounded in concrete constraints, measurable requirements, and honest assessment of implementation costs.

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