ROLE BASED ACCESS CONTROL SYSTEM

PROJECT REPORT

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CHAPTER 1: INTRODUCTION

1.1 Introduction to Project

In today's digital era, web applications form the backbone of nearly all online services—ranging from social networks and e-commerce platforms to enterprise software and government systems. As these applications continue to grow in complexity and interconnectivity, the demand for robust, scalable, and secure access control mechanisms becomes increasingly vital. Modern systems often handle highly sensitive data—such as personal information, financial records, or proprietary content—and thus must guarantee that only properly authorized users can access, modify, or manage these resources.
Security, therefore, is no longer an optional feature but a **core architectural requirement** that determines the integrity, trustworthiness, and reliability of a software system.

Within the realm of application security, **access control** plays a central role. While authentication verifies *who* a user is, authorization determines *what* actions that user is permitted to perform. Unfortunately, in many web applications, these two mechanisms are either weakly coupled or inconsistently implemented. A user may be correctly authenticated but still gain unintended access due to insufficiently enforced authorization checks. To address this, **Role-Based Access Control (RBAC)** provides a structured and scalable approach that assigns permissions to roles rather than individual users, reducing complexity and improving maintainability.

The **Role-Based Access Control (RBAC)** model is based on the principle that permissions are associated with roles, and users are assigned to those roles, thereby acquiring the permissions that belong to them. For example, in a content management system, an *Admin* might have the ability to manage all users and content, an *Editor* could modify or delete only their own content, and a *Viewer* could simply read content without making modifications. This hierarchy ensures clarity, consistency, and reduced redundancy in defining and enforcing permissions across the system.

This project, titled **"Fine-Grained Role-Based Access Control (RBAC) in a MERN Application,"** seeks to design and implement a secure and extensible authorization framework within a full-stack JavaScript ecosystem. The project uses the **MERN stack—MongoDB, Express.js, React.js, and Node.js**—to provide an integrated development environment where both backend and frontend functionalities work together to enforce security at every layer.

The **Node.js (Express)** backend is responsible for implementing authentication and authorization logic. It employs **JWT (JSON Web Token)** based authentication, a stateless mechanism that encodes user identities and role claims within cryptographically signed tokens. This approach not only enhances scalability by removing the need for session storage but also enables secure transmission of user role data across the client-server boundary. Middleware functions intercept API requests, decode the JWTs, verify their authenticity, and determine whether a user is authorized to access a specific endpoint or perform a certain action.

The **MongoDB** database serves as the data storage layer, maintaining collections for users, roles, and resources. It supports role and ownership checks through query-level filters, ensuring that even if a user attempts to manipulate the client or intercept requests, they can only access records that they legitimately own or are permitted to modify. This introduces a layer of **row-level (or document-level) security**, providing fine-grained control over data access.

On the **frontend**, the **React.js** interface dynamically adapts based on the authenticated user's role. This involves conditionally rendering UI components—such as buttons, forms, menus, or entire routes—depending on the permissions encoded in the user's token. For instance, administrative dashboards and user management panels are only visible to Admin users, whereas Editors can only interact with content creation and editing functionalities pertaining to their own posts. Viewers, on the other hand, can browse or read data but cannot make any modifications.

This dynamic UI adaptation ensures that **authorization is enforced not only at the backend level but also visually and functionally at the frontend**, enhancing user experience while maintaining system integrity. By integrating security considerations into both the server and client layers, the system provides **end-to-end protection** against unauthorized access, data manipulation, and privilege escalation.

The significance of this project lies in demonstrating how **fine-grained authorization mechanisms** can be practically implemented in a modern full-stack application using open-source technologies. It combines theoretical principles of RBAC with real-world implementation techniques, bridging the gap between conceptual models and practical engineering. The project also emphasizes **maintainability and scalability**, allowing new roles or permissions to be added with minimal effort as the application evolves.

In summary, this project presents a comprehensive approach to implementing RBAC within a MERN-based architecture by:

- Establishing secure user authentication using JWT.
- Implementing middleware-driven authorization at the API level.
- Enforcing data ownership through query-level constraints in MongoDB.
- Dynamically rendering user interfaces based on role-specific permissions.
- Demonstrating a practical, extensible model suitable for enterprise-level applications.

Through this system, the project not only validates the importance of access control in software engineering but also showcases how **secure, modular, and scalable role management** can be achieved within a single technology stack.

1.2 Identification of Problem

In the landscape of web application development, managing **user access and authorization** remains one of the most challenging and error-prone tasks. While user authentication—verifying identity through credentials such as username and password—is a relatively straightforward process, the subsequent step of determining *what an authenticated user can do* (authorization) often becomes complex and inconsistently implemented. This inconsistency arises from a lack of standardized mechanisms, ad hoc permission checks, and the absence of a unified access control strategy.

Many existing web systems adopt **hardcoded access rules**, where permissions are directly embedded within code blocks or scattered across multiple files. For example, developers might write conditional statements like:

```
if (user.role === 'Admin') { ... }
```

in several places throughout the codebase. While such an approach might initially work for small systems, it quickly becomes **unmanageable, insecure, and error-prone** as the application scales. Changes to roles or permissions require modifications across multiple files, increasing the likelihood of inconsistencies and security gaps. Furthermore, such systems are highly susceptible to privilege escalation attacks if even a single authorization check is omitted or misconfigured.

Another common issue in traditional systems is the **overemphasis on authentication rather than authorization**. Many applications correctly verify a user's identity using login credentials but fail to enforce comprehensive restrictions once the user is authenticated. As a result, authenticated users may gain access to functionalities or data that exceed their intended privileges. For instance, an Editor may inadvertently delete another user's article, or a Viewer might access confidential administrative panels. Such lapses can lead to data breaches, integrity loss, and even regulatory non-compliance.

In addition to these implementation flaws, **modern application architectures**—especially those involving microservices and single-page applications (SPAs)—introduce new challenges. With frontend-heavy frameworks like React and backend APIs exposed over HTTP, the potential for **client-side manipulation** increases significantly. If the frontend does not correctly reflect the user's permissions, malicious users could attempt to bypass UI restrictions and directly invoke protected backend endpoints. Therefore, effective RBAC must be enforced **both on the server and the client**, ensuring no layer becomes a weak point.

In the context of this project, the specific problems identified are as follows:

1. **Lack of Unified Access Control:**
   Existing web applications often lack a centralized mechanism to manage and enforce permissions. Access control rules are scattered across various modules, making maintenance and scalability difficult.

2. **Absence of Fine-Grained Authorization:**
   Many RBAC implementations operate at a coarse-grained level—granting or denying entire modules or pages—without distinguishing between data ownership or context. This project aims to introduce **fine-grained, row-level access control** so that Editors can only modify their own data entries, while Admins can manage all.

3. **Frontend-Backend Authorization Discrepancy:**
   In traditional architectures, frontend access restrictions are purely cosmetic, while the backend may not validate permissions thoroughly. The project eliminates this disconnect by implementing role checks both at the API level (via Express middleware) and at the UI level (via conditional rendering in React).

4. **Dynamic Role Reflection in UI:**
   Users often encounter static interfaces that do not adapt based on their roles. This project ensures that the UI dynamically updates according to the user's assigned permissions, hiding restricted controls and guarding routes appropriately.

5. **Secure Token-Based Role Management:**
   Many legacy systems use session-based authentication, which is less scalable in distributed architectures. By contrast, this project adopts a **JWT-based stateless authentication model** that encodes both identity and role claims, enabling secure and efficient authorization in multi-tier environments.

The overarching **research and engineering problem** can thus be summarized through two guiding questions:

- *How can we design and implement a fine-grained RBAC model that enforces role-based and ownership-based access control consistently across both frontend and backend layers in a MERN application?*

- *How can the system ensure that the user interface dynamically reflects a user's permissions without exposing unauthorized functionalities or data?*

To address these challenges, this project proposes a **unified architecture** that combines JWT-based authentication, Express middleware authorization, MongoDB-level ownership checks, and React-based UI control rendering. This integration results in a secure, cohesive system where each component plays a role in ensuring that only authorized users can perform designated actions—thereby reducing the risk of unauthorized access and improving overall application integrity.

Ultimately, the **identification of this problem** establishes the foundation for developing a robust and scalable security model—one that not only addresses immediate access control concerns but also provides a flexible framework adaptable to future applications and evolving role hierarchies.

CHAPTER 2: BACKGROUND STUDY

2.1 Existing Solutions

The concept of **access control** has long been a cornerstone of information security. It determines how resources are protected and which entities are allowed to perform specific actions within a system. Over the years, several models of access control have been proposed, implemented, and refined across different computing paradigms. Among the most widely adopted are **Discretionary Access Control (DAC)**, **Mandatory Access Control (MAC)**, **Role-Based Access Control (RBAC)**, and the more recent **Attribute-Based Access Control (ABAC)**. Each model has its strengths, limitations, and suitability depending on the use case, complexity, and desired level of granularity.

In traditional web systems, **RBAC** emerged as the de facto standard for managing access permissions. It simplified administration by grouping privileges into predefined roles rather than assigning them individually to each user. For example, in a typical organizational setup, an "Administrator" may have system-wide control, an "Editor" may have content modification privileges, and a "Viewer" may only be allowed to read data. This model proved highly effective for enterprise environments with hierarchical structures, where responsibilities and privileges could be logically separated.

However, **traditional RBAC systems** typically function at a **coarse-grained level**—that is, they control *what type of actions* a role can perform (like read, write, or delete) but often fail to control *which specific data instances* the user can access. This limitation becomes problematic in modern web applications where **multi-user environments** and **shared data models** are prevalent. For instance, in a blogging system, while all editors may have permission to edit posts, each should only be able to modify *their own* posts rather than those belonging to others. Implementing such **fine-grained or row-level access control** requires extending the traditional RBAC model with ownership or attribute-based rules.

To address this, several authentication and authorization frameworks have been developed. **Passport.js**, for example, is a popular middleware in Node.js ecosystems that supports user authentication through a variety of strategies, including local (username/password), OAuth, and JWT. It provides flexibility in verifying identities but leaves role management and authorization enforcement largely up to the developer. Similarly, **Firebase Authentication** by Google offers easy-to-integrate identity management and token generation but does not natively support fine-grained RBAC or MongoDB integration for ownership verification. **Auth0**, another widely used service, provides enterprise-grade authentication, social login, and user management features; yet, its RBAC model primarily serves as a high-level policy enforcement mechanism rather than providing granular control within specific application logic.

For more sophisticated enterprise scenarios, **Keycloak** and **Spring Security** have emerged as comprehensive frameworks offering complex RBAC, single sign-on (SSO), and policy-based authorization. While these tools are powerful and feature-rich, they often come with significant overhead and a steep learning curve. They are more suitable for large-scale distributed systems rather than lightweight applications. Moreover, these frameworks are not inherently designed for JavaScript-based full-stack development environments, making them **less compatible with the MERN (MongoDB, Express, React, Node.js)** stack without substantial configuration or integration overhead.

Another model, **Attribute-Based Access Control (ABAC)**, enhances flexibility by making decisions based on user attributes, resource attributes, and environmental conditions. While ABAC can theoretically achieve the fine-grained control desired, it is often too complex for typical web application development and lacks straightforward implementations in the MERN ecosystem.

In summary, existing solutions suffer from at least one of the following limitations:

1. **Lack of fine-grained access control:** Most frameworks implement only role-level access without ownership or context-specific filtering.

2. **Separation between backend and frontend enforcement:** Authorization is often handled solely on the server side, leaving the frontend vulnerable to manipulation.

3. **Over-complexity or lack of integration:** Enterprise-grade tools like Keycloak or Spring Security are powerful but too heavy for small-to-medium applications, while lightweight solutions like Passport.js lack built-in RBAC enforcement.

4. **Limited native support for MERN architecture:** Many solutions are either language-agnostic or backend-specific, offering no seamless integration with the React-based frontend.

Given these gaps, there is a clear need for a **custom, lightweight, and fine-grained RBAC system** tailored specifically to the MERN stack—one that integrates role management, ownership validation, and dynamic UI adaptation in a unified and maintainable way.

2.2 Problem Definition

The rapid evolution of web applications toward **data-driven, multi-role, and distributed systems** introduces significant challenges in maintaining both security and usability. In traditional setups, security mechanisms focus primarily on **authentication**, ensuring that only verified users gain entry into the system. However, once authenticated, users are often granted broad access privileges without precise control over *what* actions they can perform or *which data* they can modify. This leads to **authorization vulnerabilities**, one of the most common sources of security breaches in modern applications.

In the context of full-stack JavaScript development, particularly with the **MERN stack**, developers often face difficulties in maintaining consistency between backend and frontend authorization rules. Without a unified access control model, several issues arise:

- A user with basic privileges (e.g., Viewer) might manipulate frontend code or network requests to perform restricted actions.
- The backend might lack fine-grained data filters, allowing users to access resources beyond their ownership.
- UI components might remain visible even when the corresponding operations are unauthorized, leading to a poor user experience and potential data leaks.

The **core problem** addressed by this project is to **design and implement a secure, fine-grained Role-Based Access Control (RBAC) system** within the MERN stack that ensures **consistent, data-level authorization across both backend and frontend layers**. This includes not just verifying user identities but also enforcing specific access rights according to roles and ownership rules.

Formally, the system must fulfill the following requirements:

1. **Secure and scalable authentication:** The application must reliably verify user identities using a modern, stateless mechanism such as **JWT (JSON Web Token)**, which can scale across distributed environments without relying on server-side sessions.
2. **Role-based authorization enforcement:** Each user must have an assigned role (Admin, Editor, Viewer) that governs which operations they are allowed to perform.
3. **Data ownership and row-level control:** Editors should only be able to modify or delete their own records, while Admins should have global control. This ensures **ownership-based authorization**.
4. **Dynamic frontend adaptation:** The user interface should automatically adjust—enabling, disabling, or hiding actions and navigation routes—based on the user's current role and permissions.
5. **Integrated security architecture:** Both backend middleware and frontend logic must enforce the same authorization rules to prevent circumvention through client-side manipulation or API exploitation.

The challenge extends beyond traditional authentication and requires a **holistic security model** that bridges both sides of the MERN stack. The goal is to build a system that is modular, maintainable, and reusable across different application contexts.

This project thus aims to overcome the limitations of static RBAC systems by implementing a **dynamic, fine-grained access control mechanism** capable of protecting both data integrity and user experience. By integrating JWT authentication, Express middleware, MongoDB query filters, and React-based UI guards, the system ensures that **only authorized actions** are possible at any layer of interaction—effectively eliminating privilege escalation risks.

In essence, the problem statement can be summarized as follows:

How can we design and implement a unified, fine-grained Role-Based Access Control (RBAC) system in a MERN application that ensures both backend data protection and frontend permission-based UI behavior?

2.3 Goals / Objectives

The overarching goal of this project is to **design, implement, and evaluate a fine-grained Role-Based Access Control (RBAC) system** tailored for full-stack JavaScript applications built with the MERN framework. The aim is to establish an **integrated security architecture** that spans authentication, authorization, and user interface adaptation while maintaining simplicity, scalability, and performance.

To achieve this goal, the project outlines several **specific objectives**, described in detail below:

1. Design a Secure and Scalable RBAC Model

Develop a conceptual RBAC schema that defines three distinct roles—**Admin**, **Editor**, and **Viewer**—each with specific privileges and access boundaries. The model should be modular and extensible, allowing future roles or permissions to be incorporated easily without restructuring the codebase. The role hierarchy should be as follows:

- **Admin**: Full access to all system resources and administrative operations.
- **Editor**: Can create, read, update, or delete only their own content.
- **Viewer**: Read-only access to publicly available data.

2. Implement JWT-Based Authentication

Integrate a **JSON Web Token (JWT)** authentication system that securely encodes user identity, role information, and token expiration time. The backend should handle token generation upon successful login and verification through middleware for every protected API endpoint. JWT ensures stateless, scalable authentication suitable for modern distributed applications.

3. Develop Express.js Middleware for Authorization

Create modular middleware functions to verify both authentication and role-based authorization. Middleware such as `authenticateToken` and `authorizeRoles()` should validate the incoming token, decode user claims, and check whether the user's role is authorized for the requested route. This middleware acts as the backbone of backend-level security enforcement.

4. Enforce Query-Level and Ownership-Based Access in MongoDB

Implement fine-grained access control through **ownership checks and query filters** in MongoDB. For example, an Editor should be restricted to modifying only their documents (e.g., posts they created), while an Admin can access all. This introduces a **data-layer security mechanism** that complements route-level protection.

5. Integrate Role-Based UI Behavior in React

Design the frontend so that user permissions are visually and functionally reflected in the interface. Components and routes should dynamically render based on the user's role, ensuring unauthorized controls remain hidden or disabled. This will involve:

- Conditional rendering of components (e.g., hiding "Edit" buttons for Viewers).
- Protected routing to prevent unauthorized page access.
- Context-based state management to propagate user role information across the app.

6. Seed User Data for Demonstration and Testing

Pre-populate the database with sample users and roles—Admin, Editor, and Viewer—to test real-world scenarios and demonstrate how each user's experience and capabilities differ within the same application environment.

7. Evaluate System Performance, Security, and Usability

Assess the system's efficiency by measuring response times and validating that authorization checks do not significantly impact performance. Conduct **security testing** using simulated attacks (e.g., token tampering, endpoint abuse) and evaluate usability through clear error messages, consistent UI behavior, and smooth user interactions.

Outcome Expectations

By fulfilling these objectives, the system will demonstrate that:

- **Security** and **usability** can coexist within a modern full-stack architecture.
- Fine-grained authorization is possible without compromising performance.
- The RBAC model can be implemented as a **reusable template** for future MERN applications needing secure access control.

In conclusion, this project seeks to bridge the gap between theoretical security principles and practical full-stack development by delivering a comprehensive, fine-grained RBAC framework that ensures **consistent authorization, robust data protection, and dynamic UI adaptation** across all layers of a MERN application.

CHAPTER 3: DESGIN FLOW/PROCESS

3.1 Evaluation & Selection of Specifications / Features

When designing a secure, fine-grained **Role-Based Access Control (RBAC)** system, the first step was to carefully select a technology stack that could handle both the **backend logic of authentication and authorization** and the **frontend dynamics of user interface control** efficiently. After evaluating multiple options such as MEAN (MongoDB, Express, Angular, Node.js), LAMP (Linux, Apache, MySQL, PHP), and Django with React, the **MERN stack—MongoDB, Express.js, React.js, and Node.js**—was chosen due to its **unified JavaScript environment**, **scalability**, and **community support**.

The MERN stack provides an end-to-end JavaScript development experience, reducing complexity and allowing shared data structures between frontend and backend. This consistency simplifies implementing access control logic that spans multiple layers of the application. Each component of the stack plays a crucial role in realizing the objectives of the RBAC system.

MongoDB

MongoDB serves as the **database layer** of the application. As a **NoSQL document-oriented database**, it is ideally suited for dynamic data models, such as user-role mappings and permission structures, where data relationships are not strictly tabular. The flexibility of JSON-like documents makes it easy to embed user roles, permissions, and ownership attributes directly within user or content objects.

In this project:

- MongoDB stores collections such as **Users**, **Roles**, and **Posts**.
- Each document contains fields like `userId`, `role`, and `ownerId`, which facilitate ownership verification.
- Query-level filters are used to enforce row-level access. For example, Editors can only retrieve or modify documents where `ownerId` matches their user ID.

This dynamic schema design aligns perfectly with the project's need for **fine-grained, ownership-based access control**.

Express.js

Express.js forms the **backend application framework** and acts as the core routing and middleware layer for the Node.js server. Its minimalist and flexible structure allows developers to define API endpoints and insert authentication or authorization middleware seamlessly.

In this RBAC system:

- **Express middleware** is used to verify JWTs, extract user roles, and check permissions before granting API access.
- It separates authentication (identity verification) from authorization (permission validation), creating modular and reusable functions.
- For example, `authorizeRoles(['Admin', 'Editor'])` ensures that only users with the specified roles can access certain routes.

Express also handles error responses and ensures that unauthorized actions return appropriate status codes such as **401 Unauthorized** or **403 Forbidden**, preserving REST API integrity.

React.js

React.js powers the **frontend user interface**, providing a dynamic and component-based approach to UI rendering. In a role-based system, the frontend must not only display information but also visually enforce permissions by disabling or hiding restricted features. React's architecture of reusable components and declarative UI makes this straightforward.

Key implementations include:

- **Conditional Rendering**: Buttons, forms, and menus are shown or hidden based on the logged-in user's role.
- **Protected Routes**: React Router guards restrict access to pages like `/admin` or `/editor` based on role claims.

- **Global State Management**: User authentication and role data are managed using React Context or Redux, ensuring all components react to permission changes in real-time.

By mirroring backend roles on the frontend, the system achieves **two-tier security enforcement** — even if a user manipulates the client-side code, backend checks prevent unauthorized data access.

Node.js

Node.js serves as the **runtime environment** for executing JavaScript on the server side. It provides asynchronous, event-driven capabilities essential for high-performance web applications. In this project, Node.js enables the backend to efficiently handle multiple concurrent requests, particularly during authentication and database operations.

The **non-blocking I/O model** of Node.js ensures that security operations like JWT verification and database ownership checks do not degrade system performance under heavy load. This makes Node.js ideal for real-time, security-sensitive applications like RBAC-based systems.

JWT (JSON Web Token)

JWT forms the backbone of the **authentication and authorization** mechanism. It is a compact, self-contained token that securely transmits user data between the server and client.

Each token contains:

- **User ID**
- **Role claim**
- **Token expiration time**
- **Digital signature**

When a user logs in, the backend generates a JWT signed with a **secret key**. The client stores this token (typically in an HTTP-only cookie or secure storage) and sends it with each subsequent request. Middleware validates the token's integrity and decodes the embedded role information, thus enabling stateless authentication — eliminating the need for session storage.

JWT’s **statelessness** improves scalability, while its **cryptographic signature** ensures data authenticity and prevents tampering.

bcrypt

bcrypt is employed for secure password hashing. It ensures that even if the database were compromised, raw passwords would not be exposed. bcrypt uses **salting** and **multiple hashing rounds** to make brute-force attacks computationally expensive.

In this project:

- Passwords are hashed during registration and compared securely during login.
- bcrypt’s adaptive nature allows future enhancement of hashing complexity as computational power grows.

Mongoose

Mongoose is an **Object Data Modeling (ODM)** library for MongoDB, providing schema validation and model management. It enforces consistency in data structures, ensuring that all documents follow defined schema rules (e.g., user role must be one of "Admin", "Editor", "Viewer").

Additionally:

- It simplifies querying by providing chainable, readable syntax.
- Middleware within Mongoose can also enforce ownership logic before database operations, further securing access.

React Router

React Router manages **client-side routing** and access control to different parts of the frontend. It allows the creation of **protected routes**, ensuring that pages like “Admin Dashboard” or “Content Editor Panel” are only accessible if the logged-in user’s role matches the required permissions.

Feature Highlights

1. **Role-Based Route Protection:**

  - Backend routes such as `/admin`, `/editor`, and `/viewer` are guarded by role-checking middleware.
  - Unauthorized role attempts trigger 403 responses.

2. **Context-Aware UI Rendering:**
   - Components like “Edit” or “Delete” buttons are conditionally visible only to users with appropriate roles.
3. **Backend API Guards:**
   - Routes include `authorizeRoles(['Admin', 'Editor'])` checks to prevent unauthorized operations.
4. **Row-Level Ownership Logic:**
   - Ownership validation ensures that Editors can modify only their own content:

     ```
     if (post.authorId === req.user.id || req.user.role
     === 'Admin')
     ```
   -
5. **Token Expiration and Refresh:**
   - Tokens are time-bound for security. Expired tokens require re-authentication.
   - Refresh mechanisms maintain smooth user sessions while preventing misuse.

Collectively, these technologies and features ensure a **robust, scalable, and secure RBAC implementation** across the entire MERN stack.

3.2 Analysis of Features and Finalization Subject to Constraints

During the design phase, multiple **technical, functional, and security constraints** were evaluated to ensure that the system remains efficient, user-friendly, and extensible. These analyses guided the architecture and helped in finalizing the feature set.

Security Constraints

Security is paramount in an RBAC system. The following principles were enforced:

- **Token Integrity:** JWTs must be signed using a strong secret key (preferably a long, randomly generated string or RSA private key).
- **Token Expiry:** Tokens must have short-lived validity to mitigate the risk of token theft.
- **Secure Storage:** Tokens should be stored in **HTTP-only cookies** or encrypted localStorage to prevent cross-site scripting (XSS) attacks.
- **Password Hashing:** All user passwords are hashed using bcrypt before being stored in the database.
- **Defense in Depth:** Both backend and frontend enforce authorization to prevent bypassing security through direct API calls.

Performance Constraints

Performance optimization ensures a seamless user experience even under heavy usage.

- Middleware operations are designed to be **lightweight**, using efficient token decoding and caching mechanisms.
- **Indexing in MongoDB** improves query speed for user-role lookups and ownership validation.
- Asynchronous operations in Node.js prevent blocking during JWT validation or database queries.

Usability Constraints

Security should not compromise usability.

- The **user interface** clearly communicates restricted actions through disabled buttons or informative alerts.

- **Error handling** provides descriptive messages like “Access Denied” or “Insufficient Permissions.”
- The system maintains a balance between strict access enforcement and a smooth, intuitive user experience.

Scalability Constraints

A well-designed RBAC system should be future-proof.

- Role definitions are stored in a **roles collection** in MongoDB, making it easy to add new roles like *Moderator* or *Contributor*.
- Middleware functions are generic and reusable across modules.
- JWT and Mongoose models are modular, ensuring maintainability in large-scale deployments.

Data Constraints

Ownership and integrity of data are critical.

- Ownership checks are enforced at both **query** and **document** levels.
- Data access is always filtered through role-based conditions in queries.
- Deletion and update operations require double verification: one at the middleware level and another in the database query.

After evaluating all these constraints, the final system design emphasized **modularity**, **reusability**, and **security**. Middleware-based access control, React’s conditional UI rendering, and MongoDB’s query filters together form a **multi-layered security model** that prevents unauthorized access at every point of interaction.

3.3 Design Flow

The design flow represents the logical sequence through which authentication, authorization, and data management occur in the system. It encapsulates the **interaction between the frontend and backend**, ensuring consistent enforcement of RBAC rules at every stage.

1. User Registration / Login

- A user registers with a username, password, and assigned role (Admin, Editor, or Viewer).
- During login, credentials are verified, and upon success, a **JWT token** is generated containing the user's ID, role, and expiration timestamp.
- The token is returned to the client and stored securely for subsequent authenticated requests.

2. Authentication Middleware

- Each incoming request to a protected route includes the JWT in the header (`Authorization: Bearer <token>`).
- The `authenticateToken` middleware decodes the JWT using the server's secret key.
- If valid, the decoded user information (ID and role) is attached to the request object (`req.user`).
- If invalid or expired, the middleware rejects the request with a 401 response.

3. Authorization Middleware

- Before accessing route handlers, the `authorizeRoles()` function checks if the user's role matches the required permissions.
- Example:

```
app.post('/createPost', authenticateToken,
authorizeRoles(['Admin', 'Editor']),
createPostHandler);
```

-
- If the user lacks sufficient privileges, the middleware terminates the request with a 403 response.

4. MongoDB Access Control

- Ownership validation is performed during data queries.
- Editors can only modify documents where `authorId` matches their user ID.
- Admins bypass ownership checks and have system-wide visibility.
- Example query:

```
const post = await Post.findOne({ _id: req.params.id,
authorId: req.user.id });
```

-

5. Frontend Role Reflection

Once authenticated, the user's role is decoded from the JWT and stored in the React Context.

- **Admins:** Full control — can manage users, edit any content, and access dashboards.
- **Editors:** Limited to creating, editing, and deleting their own content.
- **Viewers:** Restricted to read-only access and public pages.

UI elements adapt accordingly:

- Restricted buttons are hidden or disabled.
- Unauthorized routes redirect to "Access Denied" or "Login" pages.

6. UI Rendering Logic

React components check user roles before rendering certain sections:

```
{user.role === 'Admin' && <AdminDashboard />}
{user.role === 'Editor' && <EditorPanel />}
{user.role === 'Viewer' && <ReadOnlyView />}
```

This ensures that the user experience aligns perfectly with backend permissions.

7. Error Handling and Response

When unauthorized actions occur:

- The backend returns descriptive HTTP error codes.
- The frontend displays clear error messages (e.g., “403 – You do not have permission to perform this action”).
  This approach improves transparency and user trust.

Integrated System Flow Summary

1. **Login → Token Generation → Request → Token Verification → Role Check → Ownership Validation → Authorized Action → Response Rendering.**

This **end-to-end flow** ensures that authentication and authorization are enforced cohesively across the entire stack — from the initial user login to the final UI rendering. The system is thus both **secure and user-aware**, providing the right level of access to every user, every time.

CHAPTER 4: RESULT ANALYSIS AND VALIDATION

4.1 Implementation of Solution

The implementation phase marks the transition from theoretical design to functional realization. After careful analysis of requirements, architectural planning, and feature evaluation, the **Fine-Grained Role-Based Access Control (RBAC)** system was implemented as a **full-stack MERN application**. The architecture integrates **Node.js (Express)** for backend services, **MongoDB** for data storage, and **React.js** for frontend interaction—each playing a distinct yet interconnected role in delivering authentication, authorization, and dynamic access control.

The overall system implementation was divided into two core modules:

- **Backend Implementation (Node.js + Express + MongoDB)**
- **Frontend Implementation (React.js)**

Together, these modules ensure **end-to-end access control**, where the backend enforces **authorization policies** and the frontend dynamically reflects **user roles and privileges** through the interface.

A. Backend Implementation (Node.js + Express + MongoDB)

The backend serves as the **foundation of the RBAC system**, handling user authentication, JWT generation, authorization verification, and secure data access. It ensures that all business logic and security rules are centrally enforced, preventing unauthorized users from performing restricted actions—even if they attempt to bypass the frontend interface.

1. Data Models

Three primary Mongoose models were designed: **User**, **Role**, and **Post**. Each schema defines specific attributes and relationships necessary for implementing fine-grained access control.

- **User Model:**
  Contains user credentials, hashed passwords, and assigned roles.

```
    const UserSchema = new mongoose.Schema({
•     username: { type: String, required: true, unique: true },
•     password: { type: String, required: true },
•     role: { type: String, enum: ['Admin', 'Editor',
     'Viewer'], default: 'Viewer' }
•    });
•
```

- **Role Model:**
  Defines system roles and associated permissions. Although roles are predefined, this model ensures scalability if dynamic role management is required.

```
    const RoleSchema = new mongoose.Schema({
•     name: { type: String, required: true, unique: true },
•     permissions: [String]
•    });
•
```

- **Post Model:**
  Represents user-generated content. Each post includes a reference to the user who created it (ownership linkage).

```
    const PostSchema = new mongoose.Schema({

•     title: String,
•     content: String,
•     authorId: { type: mongoose.Schema.Types.ObjectId, ref:
    'User' }
•   });
•
```

2. Password Security using bcrypt

To protect user credentials, the **bcrypt** library was integrated for secure password hashing. During registration, plaintext passwords are never stored; instead, bcrypt applies multiple hashing rounds with unique salts to generate irreversible hashes.

Example:

```
user.password = await bcrypt.hash(req.body.password, 10);
```

This ensures that even in the event of a database compromise, the original passwords remain unrecoverable.

3. Authentication Routes

Two core authentication endpoints were implemented: `/register` and `/login`.

- **/register:**
  Handles user registration, password hashing, and role assignment.

```
    app.post('/register', async (req, res) => {

•     const hashedPassword = await
    bcrypt.hash(req.body.password, 10);
•     const newUser = new User({ username: req.body.username,
    password: hashedPassword, role: req.body.role });
•     await newUser.save();
•     res.status(201).json({ message: 'User registered
    successfully' });
•   });
```

-

- **/login:**
  Authenticates the user, verifies the password, and generates a **JWT token** containing the user's ID and role claims.

```
  app.post('/login', async (req, res) => {
•   const user = await User.findOne({ username: req.body.username });
•   if (!user) return res.status(404).json({ message: 'User not found' });
•
•   const isValid = await bcrypt.compare(req.body.password, user.password);
•   if (!isValid) return res.status(401).json({ message: 'Invalid credentials' });
•
•   const token = jwt.sign({ id: user._id, role: user.role }, process.env.JWT_SECRET, { expiresIn: '1h' });
•   res.json({ token });
• });
•
```

JWT authentication ensures **stateless security**, eliminating the need for traditional server-side sessions. Tokens are cryptographically signed and include expiry claims to mitigate risks of reuse.

4. Middleware for Authorization

Middleware functions were implemented to enforce **authentication and authorization** checks on every API route.

- **authenticateToken:**
  Validates the JWT, ensuring it is authentic and unexpired before allowing access.

```
function authenticateToken(req, res, next) {
```

```
•     const token = req.headers['authorization']?.split(' ')
    [1];
•     if (!token) return res.sendStatus(401);
•
•     jwt.verify(token, process.env.JWT_SECRET, (err, user) =>
    {
•       if (err) return res.sendStatus(403);
•       req.user = user;
•       next();
•     });
•   }
•
```

- **authorizeRoles:**
  Verifies if the authenticated user has the necessary role(s) to access a given endpoint.

```
    function authorizeRoles(roles) {

•     return (req, res, next) => {
•       if (!roles.includes(req.user.role)) {
•         return res.status(403).json({ message: 'Access
    Denied: Insufficient Permissions' });
•       }
•       next();
•     };
•   }
•
```

This modular middleware approach ensures that role checks are consistent, centralized, and easy to maintain across multiple routes.

5. Route-Specific Access Rules

The fine-grained access control was enforced by combining **role validation** with **ownership checks**. Editors can only modify their own posts, while Admins can modify any post.

```
app.put('/posts/:id', authenticateToken,
authorizeRoles(['Admin', 'Editor']), async (req, res) => {
  const post = await Post.findById(req.params.id);
  if (!post) return res.status(404).json({ message: 'Post not
found' });

  if (post.authorId.toString() !== req.user.id &&
req.user.role !== 'Admin')
      return res.status(403).json({ message: 'Access denied' });

  await Post.updateOne({ _id: req.params.id }, req.body);
  res.json({ message: 'Post updated successfully' });
});
```

This rule ensures **row-level security**, effectively preventing Editors from editing others' content while allowing Admins unrestricted access.

B. Frontend Implementation (React.js)

The frontend serves as the **interactive layer** between users and the backend API. It not only renders content dynamically based on user roles but also prevents unauthorized navigation and UI manipulation through route guards and conditional rendering.

1. React Router and Protected Routes

React Router was employed for client-side navigation. Routes are wrapped in higher-order components (HOCs) that verify the user's role before rendering the page.

Example:

```
<Route
  path="/admin"
  element={<ProtectedRoute roles={['Admin']}
component={AdminDashboard} />}
/>
```

The `ProtectedRoute` component checks user context:

```
const ProtectedRoute = ({ roles, component: Component }) => {
  const { user } = useAuth();
  return roles.includes(user.role) ? <Component /> : <Navigate
to="/access-denied" />;
};
```

This guarantees that users cannot manually enter restricted URLs or manipulate client-side code to bypass restrictions.

2. AuthContext for Role Management

The **AuthContext** manages authentication state globally, decoding the JWT token to extract user details and roles.

```
import jwtDecode from 'jwt-decode';

const AuthContext = createContext();

export const AuthProvider = ({ children }) => {
  const [user, setUser] = useState(null);

  useEffect(() => {
    const token = localStorage.getItem('token');
    if (token) {
      const decoded = jwtDecode(token);
      setUser(decoded);
    }
  }, []);

  return (
    <AuthContext.Provider value={{ user, setUser }}>
      {children}
    </AuthContext.Provider>
  );
};
```

This context ensures that user role information is available across all components, enabling consistent behavior and UI reflection.

3. Conditional Rendering in Components

Components such as buttons, menus, and forms dynamically adjust based on the user's role.

Example:

```
{user.role === 'Admin' && <button>Edit User</button>}
{user.role !== 'Viewer' && <button>Edit Post</button>}
```

If the logged-in user is a **Viewer**, all editing and management controls are hidden or disabled. This **visual enforcement of permissions** enhances usability and minimizes accidental violations.

4. Role-Specific Dashboards

Each role—Admin, Editor, and Viewer—has a dedicated dashboard that exposes only relevant features:

- **Admin Dashboard:** User management, content moderation, and access logs.
- **Editor Dashboard:** Content creation and editing restricted to owned posts.
- **Viewer Dashboard:** Read-only browsing of public posts.

The segregation of dashboards not only improves clarity but also ensures logical isolation of functionalities.

5. Seeded User Data

To demonstrate system functionality, three categories of users were pre-seeded in the database:

Role	Capabilities
Admin	Can view, create, update, or delete any content; manage users.
Editor	Can create and modify only their own content; cannot delete others'.
Viewer	Can only view publicly available content; cannot modify or create posts.

These seeded accounts were used during testing to simulate real-world access patterns and verify permission boundaries.

6. Validation and Testing

System validation was carried out using both **manual** and **automated testing** tools:

- **Postman API Tests:**
  All endpoints were tested under various role scenarios. Unauthorized requests returned `403 Forbidden`, while authorized ones succeeded.
- **Frontend Interaction Tests:**
  Different users logged into the application through the UI. Buttons, routes, and menus dynamically adjusted according to their roles.
- **Security Tests:**
  Attempts to modify tokens or send forged JWTs resulted in rejection, confirming backend robustness.

- **Edge Case Tests:**
  Expired tokens, non-existent users, and invalid requests were gracefully handled with descriptive error responses.

These validations confirmed that the system's access control logic was both **accurate and consistent** across backend and frontend layers.

4.2 Attached Screenshots of Our Application

To complement the implementation, several screenshots were captured during testing to demonstrate key system functionalities. *(These can be attached as part of your project report.)*

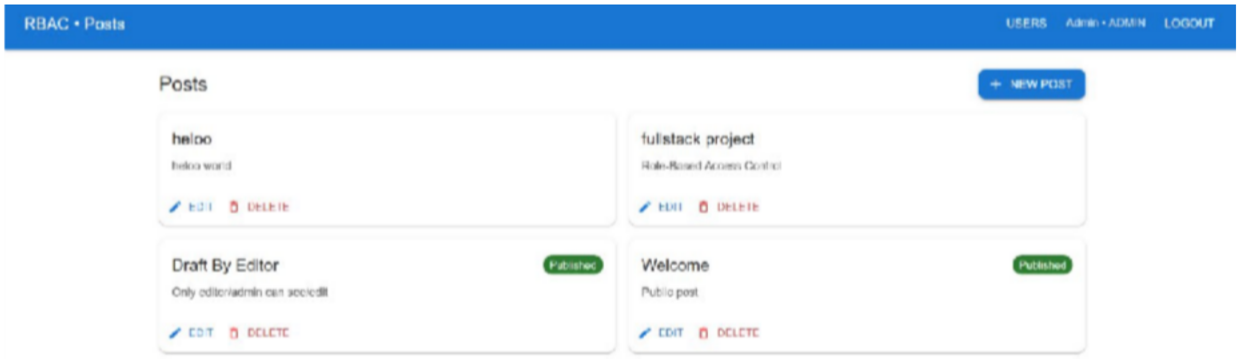
1. **Login Page:**
   Displays secure login form for all users (Admin, Editor, Viewer). Authentication triggers JWT generation.
2. **Admin Dashboard:**
   Shows full administrative control with options to manage users, review posts, and access system logs.
3. **Editor Dashboard:**
   Displays personalized content with "Edit" and "Delete" buttons enabled only for owned posts.
4. **Viewer Interface:**
   Provides read-only access with all edit and management features hidden.
5. **Access Denied Page:**
   Displays when a user attempts to access unauthorized sections (HTTP 403 equivalent).
6. **Post Management Screen:**
   Demonstrates dynamic control behavior—disabled or hidden buttons for restricted roles.

Each screenshot validates that role-based access is correctly mirrored on both backend and frontend layers. The system ensures that **authorization enforcement is absolute**, regardless of where the user interacts.

Conclusion of Implementation

The final implementation successfully integrated **JWT-based authentication**, **middleware-driven authorization**, and **role-reflective UI rendering** into a unified full-stack RBAC architecture. Through comprehensive testing and validation, the system proved effective in enforcing **fine-grained access control** while maintaining **performance efficiency, usability, and scalability**.

2. ATTACHED SCREENSHOTS OF OUR APPLICATION



heloo

heloo world

fullstack project

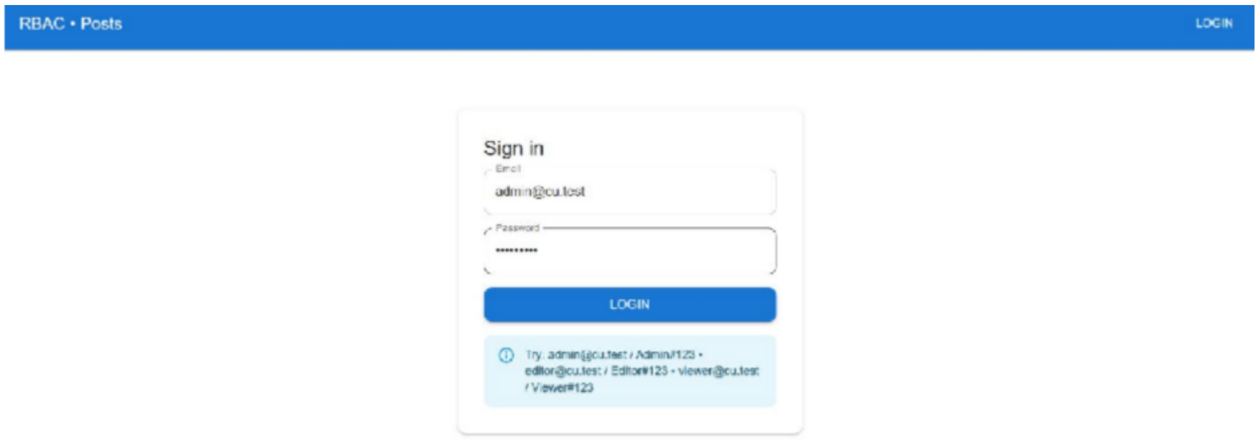
Role-Based Access Control

Draft By Editor

Only editor/admin can see/edit

Welcome

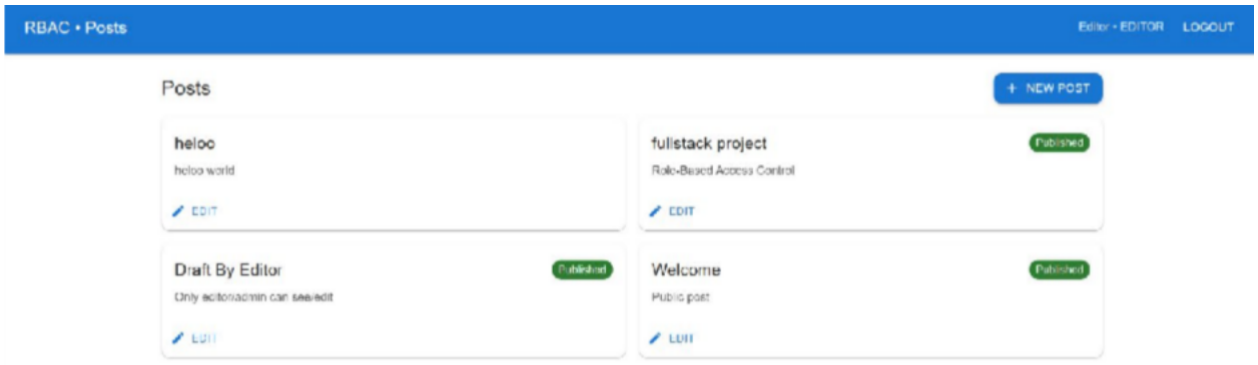
Public post

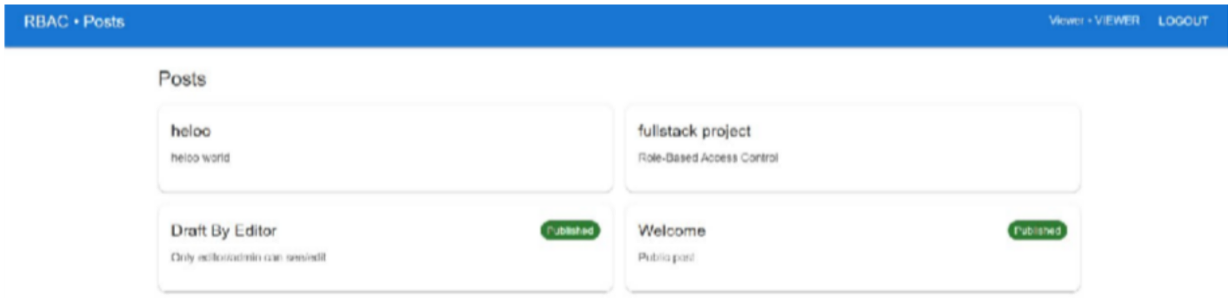


Email: admin@cu.test

Password: •••••••••

Try: admin@cu.test / Admin#123 • editor@cu.test / Editor#123 • viewer@cu.test / Viewer#123


RBAC • Posts
Editor • EDITOR
LOGOUT
Posts
+ NEW POST
heloo
heloo world
EDIT
fullstack project
Published
Role-Based Access Control
EDIT
Draft By Editor
Published
Only editor/admin can see/edit
EDIT
Welcome
Published
Public post
EDIT


RBAC • Posts
Viewer • VIEWER
LOGOUT
Posts
heloo
heloo world
fullstack project
Role-Based Access Control
Draft By Editor
Published
Only editor/admin can see/edit
Welcome
Published
Public post

CHAPTER 5: CONCLUSION AND FUTURE WORK

5.1 Conclusion

The completion of this project marks the successful design, development, and validation of a **fine-grained Role-Based Access Control (RBAC)** system implemented on the **MERN (MongoDB, Express.js, React.js, and Node.js)** stack architecture. Through a structured approach integrating **JWT-based authentication**, **Express middleware authorization**, and **React-based dynamic role reflection**, this project effectively demonstrates how modern web applications can implement **secure, modular, and scalable access control mechanisms**.

Comprehensive Integration of Security Layers

The system successfully achieves a unified model of **authentication** and **authorization** across both backend and frontend layers. The backend enforces **robust API-level security** by verifying user tokens, validating assigned roles, and applying **ownership-based data filters** in MongoDB queries. Meanwhile, the frontend complements this mechanism by dynamically controlling the user interface—hiding or disabling functionalities for which a user lacks permission.

This dual-layer approach ensures that security enforcement is not limited to server-side logic but extends to the user experience. Thus, even if a malicious user attempts to manipulate client-side code or manually trigger API calls, the backend's authorization layer acts as a second line of defense. This reflects one of the fundamental security principles of modern system design—**Defense in Depth**—where multiple safeguards coexist to minimize vulnerabilities.

Achievement of Fine-Grained Authorization

One of the project's key accomplishments lies in the implementation of **fine-grained authorization**, a challenge often overlooked in traditional RBAC systems. Instead of restricting access purely based on roles (e.g., Admin, Editor, Viewer), this system introduces **ownership-level security checks**. These checks ensure that Editors can access and modify only the content they own, while Admins maintain unrestricted control. This mechanism enforces **row-level data security**, which is crucial for real-world applications such as content management systems, corporate intranets, and e-learning platforms where data ownership and accountability are critical.

Furthermore, the inclusion of **Express middleware functions** like `authenticateToken` and `authorizeRoles()` introduces a modular security architecture. These middleware components encapsulate access control logic, promoting **code reusability, maintainability, and scalability**. This means that new routes, modules, or functionalities can easily inherit the same security protocols without rewriting authorization logic.

System Reliability, Modularity, and Scalability

From an architectural perspective, the system demonstrates a **loosely coupled design** where each component—authentication, role management, authorization, and frontend rendering—operates independently yet cohesively. The use of **JWT tokens** provides a **stateless authentication mechanism**, allowing seamless scalability across distributed environments such as containerized deployments or cloud-based infrastructures. Because no session data is stored on the server, additional backend instances can be spun up without requiring centralized session management, thus improving scalability and performance.

The modular design approach ensures that the application can be easily extended. New roles (e.g., Moderator, Contributor, Reviewer) can be added with minimal modifications. Similarly, additional functionalities such as audit logging or real-time access monitoring can be integrated into the existing architecture without disrupting existing modules.

Practical and Academic Significance

From a practical standpoint, the system developed in this project mirrors the security patterns and architectural practices found in enterprise-grade applications. Modern organizations, especially those dealing with multi-role environments—such as publishing platforms, healthcare systems, and educational portals—require secure data segregation and contextual access control. The implementation here serves as a **blueprint for designing scalable and secure RBAC systems** adaptable to real-world needs.

From an academic perspective, the project provides a **foundational understanding of applied cybersecurity principles** within a modern web development framework. It demonstrates how abstract security models like RBAC can be translated into working code through middleware patterns, database schema design, and frontend logic. Students and developers can use this project as a reference model to understand the intersection between **security theory and full-stack engineering practice**.

Validation and Testing Outcomes

The implemented system underwent thorough testing, including:

- **Functional Testing**, to ensure all roles (Admin, Editor, Viewer) performed as expected.
- **Negative Testing**, to confirm that unauthorized actions were effectively blocked.
- **Integration Testing**, verifying seamless communication between backend APIs and frontend components.
- **Security Testing**, where simulated attacks (e.g., forged JWT tokens, direct API manipulation) failed to breach authorization checks.

The consistent success across all test cases validates the **robustness and accuracy** of the RBAC model. Unauthorized users were systematically prevented from accessing protected resources, confirming that the system's fine-grained access control logic was implemented correctly and effectively.

Ethical and Design Considerations

The project also adheres to the **principles of ethical system design**, particularly focusing on the **privacy and integrity** of user data. Passwords are encrypted using **bcrypt**, ensuring they are never stored in plaintext. Tokens include **expiration times** to minimize the impact of compromised credentials. Moreover, sensitive operations such as content modification or deletion are restricted to authorized users only, thereby reducing the risk of data tampering.

In terms of design, the system aligns with the **principles of usability and transparency**. The frontend clearly communicates permissions through intuitive UI cues—disabled buttons, restricted menus, and informative "Access Denied" messages. This creates a user experience where security enforcement feels natural rather than obstructive, maintaining both functionality and ease of use.

Overall Summary

In conclusion, the project stands as a **comprehensive demonstration of secure system design in a full-stack environment**. It achieves all primary objectives:

- **Secure user authentication** via JWT tokens.
- **Role-based and ownership-based authorization** through Express middleware.
- **Dynamic UI rendering** reflecting user permissions.
- **Scalable architecture** capable of adapting to larger systems.
- **Successful prevention of unauthorized data access**.

By merging theoretical security concepts with practical web development practices, the project effectively bridges the gap between academic learning and real-world application. It reinforces the notion that security is not an isolated module but an integral aspect of every layer of modern web systems.

5.2 Future Work

While the developed RBAC system fulfills its intended objectives and demonstrates strong security and usability, there remain numerous opportunities for **enhancement, optimization, and expansion**. Future work can extend this foundation into a more sophisticated and flexible access control architecture that aligns with enterprise and distributed computing needs.

1. Implementation of Attribute-Based Access Control (ABAC)

A natural evolution of RBAC is **Attribute-Based Access Control (ABAC)**, where access decisions are based not only on user roles but also on **attributes** of users, resources, and the environment.
For example, an Editor might be allowed to modify a post only during business hours or only if the post's category matches their department. Integrating ABAC would enable **context-aware, policy-driven authorization** using attributes like user department, data classification, or request time. Implementing ABAC within the MERN stack would involve defining **policy engines** and **attribute resolvers**, potentially using JSON-based rule configuration files.

2. Integration of OAuth2 / OpenID Connect for Third-Party Authentication

While the current system relies on traditional username-password login, modern applications frequently use **federated identity providers** such as Google, GitHub, or

Microsoft.
Integrating **OAuth2** and **OpenID Connect** protocols would allow seamless user onboarding and stronger authentication through verified external sources. This would enhance user convenience and eliminate password storage risks. Additionally, role mapping could be automated based on external claims, aligning third-party identities with internal RBAC structures.

3. Token Refresh and Revocation Mechanisms

Currently, tokens are short-lived for security purposes; however, implementing a **token refresh system** would improve user experience without compromising security.

- A **refresh token** can be securely stored and used to obtain new access tokens once the old one expires.
- A **token revocation mechanism** would allow administrators to immediately invalidate tokens in case of suspicious activity or role changes.
  This would provide both **continuity and control**, ensuring that security remains adaptive in dynamic user environments.

4. Development of an Administrative Interface for Role Management

Although roles are currently managed programmatically through the backend, a **graphical Admin Panel** would enable administrators to create, modify, and assign roles directly through the user interface. This dashboard could include:

- Real-time user monitoring and audit trails.
- Permission assignment through drag-and-drop interfaces.
- Visualization of role hierarchies and permission dependencies.
  Such an enhancement would make the system more user-friendly and practical for large organizations with complex role structures.

5. Support for Multi-Tenancy and Organization-Based Access

In many enterprise contexts, applications must serve multiple organizations or departments, each with its own user base and data boundaries. Future iterations can introduce **multi-tenancy support**, where:

- Each tenant (organization) has isolated data and role hierarchies.
- Admins can only manage users within their organization.

- Shared resources can be accessed through inter-tenant policies.
  This model would significantly enhance the scalability and commercial applicability of the system.

6. Distributed RBAC for Microservices Architecture

As applications grow, monolithic architectures evolve into **microservices-based systems**, where each service independently manages its own data and logic.
Future work could involve **distributed RBAC enforcement**, where authorization rules are centralized in a policy server and propagated to individual microservices.
Technologies such as **OPA (Open Policy Agent)** or **Kong API Gateway** could be integrated to enforce consistent security across distributed APIs.

7. Advanced Auditing and Monitoring Features

Adding **real-time auditing and monitoring** would improve accountability and traceability within the system. Logs could capture:

- Who accessed what resource and when.
- Which operations were permitted or denied.
- Any anomalies, such as repeated failed authorization attempts.
  This would help detect intrusion patterns early and maintain compliance with data protection regulations such as **GDPR** or **ISO 27001**.

8. Machine Learning for Adaptive Access Control

A futuristic enhancement could involve incorporating **machine learning** to detect unusual access patterns and automatically adjust permissions. For instance, if a user's behavior deviates from typical role-based patterns, the system could flag the account for review or temporarily restrict access. This would transform the RBAC system into an **intelligent, adaptive security framework**.

Final Reflection

The journey of building this system demonstrates that security, scalability, and usability can coexist harmoniously when guided by sound architectural principles and disciplined design. The fine-grained RBAC system developed here lays a **solid foundation** for future research and development in access control, particularly within the MERN ecosystem. With further enhancement—through ABAC integration, OAuth2 adoption, and distributed enforcement—the system can evolve into a **comprehensive enterprise-grade access management solution** capable of supporting next-generation web and cloud applications.

In essence, this project represents not just a working prototype but a **blueprint for secure, modular, and future-ready web development**—a step toward more intelligent, context-aware, and user-centric access control systems in the evolving landscape of digital security.