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A WEB-BASED PLATFORM FOR DISASTER MANAGEMENT

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ABSTRACT
Conventional approaches to resource allocation in disaster response management are often characterized by inefficiency and inadequacy, particularly in rapidly evolving disaster situations. Implementing a data-driven framework can significantly improve disaster response by assessing existing models, creating a cohesive framework that incorporates decision support systems, and testing its efficacy through simulations. Developing a Progressive Web App (PWA) utilizing contemporary web technologies and data analytics enhances coordination and the deployment of resources. This PWA enables real-time data integration and optimizes resource allocation, highlighting the transformative potential of computer science in disaster management. Future initiatives should focus on harnessing artificial intelligence and machine learning to further enhance resource allocation strategies and predictive analytics.

Keywords: *Web-Based Platform, enables real-time data integration, artificial intelligence*

INTRODUCTION

Natural disasters, including earthquakes, tsunamis, floods, hurricanes, and volcanic eruptions, have historically inflicted significant damage and continue to pose risks to infrastructure and millions of individuals annually (Felix, *et al.*, 2014). The response phase in natural disaster management is particularly crucial for minimizing casualties and economic impacts. During this phase, numerous incidents, such as fires and structural collapses, necessitate immediate attention from rescue teams, often under conditions of severe resource limitations and time constraints. Consequently, one of the most vital tasks in emergency response (Cvetković, *et al.*, 2024), (Abazari, *et al.*, 2021) is the effective allocation and scheduling of rescue personnel.

In the realm of disaster management, disasters are characterized as large-scale disruptions that significantly exceed a community's capacity to manage them with its available resources. These events can occur suddenly and with great intensity, as seen in earthquakes or hurricanes, or they may develop gradually over time, such as in the case of droughts or famines. Analyzing the fundamental elements of disasters within this framework reveals three key dimensions: scale, severity, and the potential to overwhelm local capabilities. In terms of scale, disasters typically affect extensive areas and large populations (Cao *et al.*, 2021). For instance, while a house fire is undoubtedly tragic, it does not meet the criteria for a disaster in this context. The damage inflicted by disasters is considerable, encompassing human losses (fatalities, injuries), economic impacts (destruction of infrastructure, disruption of businesses), and environmental consequences (land degradation, pollution), which underscores their often devastating nature. A defining feature of a disaster is its capacity to exceed the affected community's ability to respond and recover independently. This inability may stem from insufficient resources (such as personnel, equipment, and supplies), damage to infrastructure, or a combination of these factors, highlighting the potential for disasters to overwhelm local capacities (Gil-Rivas, & Kilmer 2016), (Norris, *et al.*, 2008), (Kusumasari, *et al.*, 2010).

Disasters are increasingly frequent and inflicting greater damage than ever before, primarily due to climate change and the rising urban population. Consequently, there is an urgent need to enhance disaster management strategies. This project aims to investigate the application of computer science in optimizing resource allocation during disaster response and management. Natural disasters, including earthquakes, tsunamis, floods, hurricanes, and volcanic eruptions, have historically inflicted significant harm and continue to pose threats to infrastructure and millions of individuals annually (Amezquita-Sanchez, *et al.*, 2017). The response phase of natural disaster management is particularly crucial for minimizing casualties and economic impacts, as it involves addressing numerous incidents, such as fires and structural collapses, that demand immediate attention from rescue teams amidst severe resource limitations and time constraints. Therefore, one of the most vital tasks in emergency response is the effective allocation and scheduling of rescue resources (Wei, 2021), (Chaudhary & Piracha, 2021), (Velotti, 2021).

Efficient resource allocation is essential for effective disaster management. Disasters disrupt lives and damage infrastructure, leading to urgent demands for personnel, equipment, and supplies. However, conventional methods often face challenges in effectively distributing limited resources in response to rapidly changing needs during large-scale emergencies. This literature review examines current research on resource allocation models and underscores the potential of advancements in computer science to enhance disaster response efforts.

Numerous scholars have put forth various models aimed at enhancing resource allocation efficiency. (Altay, 2013) introduced two integer programming models designed to tackle the complexities associated with the distribution of multiple emergency resources. Nonetheless, these models do not account for potential conflicts that may arise from the simultaneous utilization of identical resource types.

(Arora, Raghu & Vinze 2010) focused on resource allocation amidst significant healthcare demands during disaster response scenarios. Their research indicated that postponing decisions related to pre-allocation could enhance flexibility in managing pandemics, thereby facilitating a more effective response. However, their analysis was limited to a single rescue agency and a singular type of emergency resource.

(Chen & Miller-Hooks 2012) developed a mathematical framework for the optimal deployment of urban search and rescue teams in the aftermath of disasters. They proposed a column generation strategy that involved addressing a series of interconnected two-stage stochastic programs with recourse, all while operating within a diminishing time frame to mitigate computational challenges.

(Geroliminis, *et al.*, 2011) introduced a hypercube spatial queuing

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model along with a heuristic solution derived from genetic algorithms, aimed at the optimal deployment of multiple emergency response units within urban transportation networks.

Han, Guan, and Shi (2011) created a methodology grounded in the successive resolution of subproblems within a Lagrangian relaxation framework. This approach optimized route capacity and site selection in emergency relief operations, effectively alleviating congestion resulting from heavy traffic.

(Huang & Fan 2011) examined the challenge of distributing multiple emergency service resources to protect essential transportation infrastructure. They utilized deterministic stochastic programming to represent various risk preferences in decision-making amidst uncertain service availability and accessibility.

In a related study, (Huang, *et al.*, 2007) developed a mixed-integer linear programming model aimed at optimizing the allocation of limited emergency service vehicles, such as fire engines, fire trucks, and ambulances, across a selection of candidate stations to enhance service coverage for critical transportation infrastructure.

Further advancing this field, (Huang, *et al.*, 2015) created an integrated multi-objective optimization model to address the humanitarian goals associated with the allocation and distribution of emergency resources during disaster response operations. Their approach included a time-space network to facilitate frequent updates of information and decisions within a rolling horizon framework. However, their methodology employed the weighted sum method to merge multiple objectives, thereby categorizing their approach as a single-objective optimization technique.

(Kondaveti & Ganz 2009) presented a decision support system designed to allocate resources from public emergency services to aid victims. They applied linear programming to derive an optimal solution for resource deployment and dispatching, relying on rapid information gathering from emergency response service agencies.

(Xin, *et al.*, 2007) developed a mathematical model prioritizing emergency response time over cost considerations. They devised a comprehensive resource allocation strategy to address conflicts by modifying the distribution of resources across various disaster sites.

(Wex, *et al.*, 2014) formulated a mixed-integer nonlinear model for the allocation and scheduling of rescue units. They also proposed several heuristic improvements and employed the GRASP (greedy randomized adaptive search procedure) metaheuristic to reduce the total incident completion times, weighted by severity. Nonetheless, their methodology is confined to a single category of emergency resource.

The existing literature typically operates under the assumption that the emergency resources of each rescue agency are either boundless, allowing for complete fulfillment of all incident requirements, or that resources are allocated serially based on the priority of each incident. While these strategies may be effective in certain emergency situations discussed in the literature, they do not reflect the reality of most practical scenarios, where the emergency resources of rescue agencies are significantly limited. Furthermore, the serial allocation of these resources often results in diminished effectiveness and efficiency.

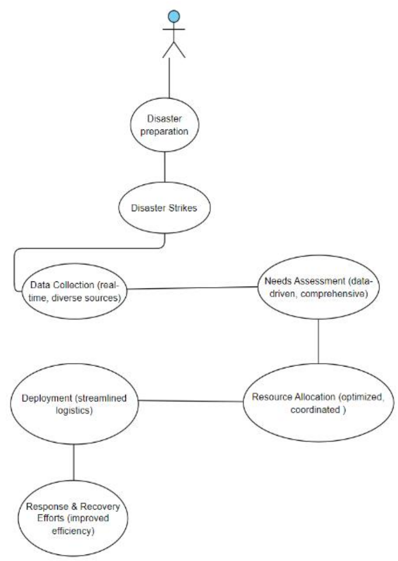

Figure 1: Use Case Diagram for Proposed System

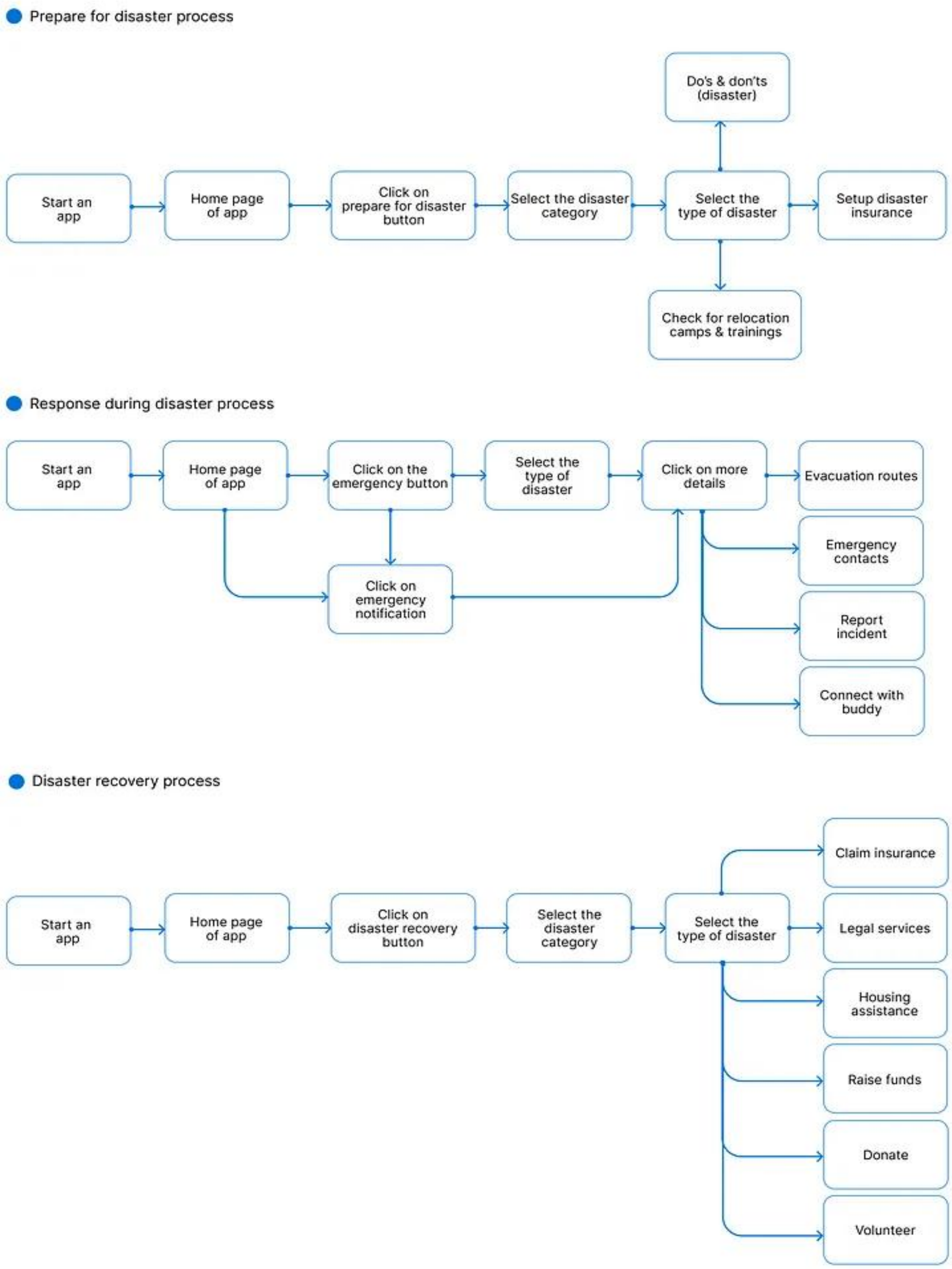

Figure 2: Task Flow for Proposed System

MATERIALS AND METHODS
Backend Development

i. **Next.js API Routes:** Next.js API routes were developed to handle functionalities like user authentication, data manipulation (CRUD operations – Create, Read, Update, Delete) on the database, and handling requests from the frontend components.

ii. **Database Integration:** A database management system (DBMS) like PostgreSQL or MongoDB was chosen to store disaster data, resource information, user accounts, and other relevant data.

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iii. **Security Considerations:** Secure coding practices and security frameworks were implemented to protect against vulnerabilities, data breaches, and unauthorized access. User authentication and authorization mechanisms were established to control access to sensitive data

Data Collection

Data utilized by the PWA can be sourced from various strategies:

i. **Internal Data Collection:** The PWA can have functionalities for users to input data relevant to disaster events, resource availability (personnel, equipment, supplies), and damage assessments. This user-generated data can be supplemented with:
ii. **Disaster Information APIs:** Integration with APIs from government agencies or disaster response organizations can provide real-time data on ongoing disasters, including location, severity, and estimated impact.
iii. **Open Data Sources:** Openly available datasets on population demographics, infrastructure maps, and historical disaster events can be valuable resources for the PWA.

Web Design

i. **Responsive Design:** As mentioned earlier, responsive design principles are crucial. The PWA should adapt seamlessly to various screen sizes and devices – desktops, laptops, tablets, and smartphones – ensuring accessibility for users in diverse environments, including those with limited internet bandwidth.
ii. **Data Visualization:** Effective use of data visualization techniques like interactive maps, charts, and graphs is essential for users to comprehend complex disaster data and resource allocation information quickly.
iii. **Minimalist and User-Friendly Interface:** A clean and uncluttered user interface with clear navigation and intuitive functionalities is paramount. This ensures users can access critical information and perform resource allocation tasks efficiently, even under stressful disaster response situations.

Database

The choice of database management system (DBMS) depends on factors like data volume, scalability needs, and desired functionalities. Below are two potential options:

i. **PostgreSQL:** A robust, open-source relational database management system (RDBMS) well-suited for handling structured data like disaster information, resource inventories, and user accounts. It offers strong security features and scalability for handling large datasets.
ii. **MongoDB:** A popular NoSQL document database that excels in storing and manipulating semi-structured data. It can be a good choice if the data schema may evolve over time or if the data has a complex hierarchical structure.

Programming Language

TypeScript/JavaScript is the primary programming language used for Next.js development. Here is a breakdown of its usage:

i. **Frontend (Client-Side):** TypeScript with libraries like React is used to build the PWA's interactive components and user interface elements. Next.js provides additional functionalities for data fetching, routing, and server-side rendering.
ii. **Backend (Server-Side):** TypeScript with Node.js is employed to develop the backend functionalities like API routes for data handling, user authentication, and communication with the database.

User Interface (UI) Development

i. **Component-Based Architecture:** Utilize a framework like tailwindCSS to build reusable and customizable UI components for various functionalities like data visualization, forms, and user dashboards.
ii. **Interactive Data Visualization:** Integrate libraries like D3.js or Chart.js to create interactive charts, maps, and graphs for displaying disaster data, resource allocation statistics, and other relevant information.
iii. **Accessibility Considerations:** Employ accessibility best practices like using semantic HTML, providing alternative text descriptions for images, and ensuring proper keyboard navigation to cater to users with disabilities.

Data Management

i. **Database Schema Design:** Design a database schema that efficiently stores disaster data, resource information, user accounts, and other relevant data points. This schema should consider data relationships, data integrity, and scalability requirements.
ii. **Object Relational Mapping (ORM):** Utilize an ORM like Typeorm, Sequelize or Mongoose to simplify database interactions within the Next.js backend code. ORMs provide a higher-level abstraction for interacting with the database, reducing boilerplate code and improving maintainability.
iii. **Data Validation and Security:** 1. It is essential to establish comprehensive data validation processes on both the client-side and server-side to maintain data integrity and mitigate the risk of harmful data entry. Additionally, the adoption of secure coding methodologies and the implementation of user authentication protocols are crucial for safeguarding against possible security threats.

API Development

Develop API routes using Next.js to handle various functionalities like:

i. User registration and login functionalities.
ii. CRUD operations (Create, Read, Update, Delete) on data stored in the database (e.g., adding new resource entries, updating disaster information).
iii. Data fetching requests from the frontend components to retrieve relevant disaster and resource allocation information.

Implement authentication and authorization mechanisms for API access to ensure only authorized users can perform specific actions. Secure coding practices and input validation should be applied to prevent potential security risks.

Testing and Deployment

1. **Unit Testing:** Implement unit testing frameworks like Jest to write unit tests for individual frontend components and backend API routes. Unit tests ensure the functionality of each component and API route in isolation, promoting code quality and maintainability.
2. **Integration Testing:** Conduct integration testing to verify how different components and functionalities of the PWA work together. This can involve testing user flows, data interactions between frontend and backend, and overall system behavior.
3. **End-to-End Testing (E2E):** Utilize E2E testing frameworks like Cypress or Playwright to simulate real user interactions with the PWA. E2E testing helps identify potential issues in the overall user experience and ensures the PWA functions as intended under various scenarios.
4. **Deployment:** Choose a suitable deployment platform like Vercel, Netlify, or AWS Amplify for deploying the PWA. These platforms offer streamlined deployment processes, automated builds, and integration with popular cloud providers.

Performance Optimization

1. **Code Splitting:** Next.js offers code splitting techniques to break down the PWA's codebase into smaller bundles. This reduces initial load times and improves performance, especially for users with limited bandwidth.
2. **Image Optimization:** Optimize images used in the PWA to reduce their file size without compromising visual quality. Techniques like lazy loading can be employed to load images only when they come into view, further improving performance.
3. **Caching Mechanisms:** Utilize browser caching mechanisms to store frequently accessed data and resources locally on the user's device. This can significantly improve performance for repeat visits and offline functionality.

PROJECT MANAGEMENT TOOLS

Throughout the development process, various project management tools can be utilized to streamline development workflows, collaboration, and version control:

1. **Version Control System (VCS):** A VCS like Git allows for version control of the codebase, enabling developers to track changes, revert to previous versions if necessary, and collaborate effectively on different parts of the code.
2. **Project Management Software:** Tools like Asana, Trello, or Jira can be used to manage project tasks, track progress, assign responsibilities, and facilitate communication within the development team.
3. **Communication Tools:** Platforms like Slack or Microsoft Teams offer real-time communication channels for developers to collaborate, discuss technical challenges, and share updates.

Ethical Considerations

Developing a PWA for disaster management necessitates careful consideration of ethical implications:

1. **Data Privacy:** User data collected by the PWA, such as disaster location details or resource availability, must be treated with utmost confidentiality. Secure storage practices and user consent mechanisms should be implemented to comply with relevant data privacy regulations.
2. **Data Security:** Robust security measures are essential to protect sensitive data from unauthorized access, breaches, or manipulation. This includes secure coding practices, regular security audits, and vulnerability assessments.
3. **Algorithmic Bias:** Algorithms used within the PWA for data analysis or resource allocation should be carefully evaluated for potential biases. Measures should be taken to mitigate biases that could disadvantage certain populations or communities during disaster response.

By adhering to these ethical considerations, the PWA can be a valuable tool for optimizing resource allocation in disaster management while protecting user privacy and ensuring fair and equitable distribution of resources. The methodology emphasizes user-centered design, data-driven decision-making, secure backend functionalities, and performance optimization for efficient disaster response. By following these methodological guidelines, and carefully considering ethical implications, the developed PWA can become a powerful tool for disaster management organizations to optimize resource allocation and improve disaster response effectiveness.

RESULTS

To use the PWA, a user navigates to the url for the web app: https://shieldd.vercel.app. They are greeted with the main page of the app with a prominent banner instructing or prompting the user to install the app as a PWA if they are on an android device or PC and instructions to add the app to the home screen if they are on an ios device.

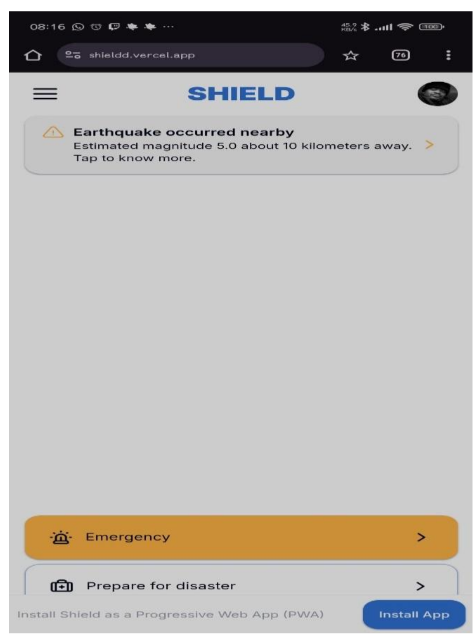

Figure 3: Landing Page

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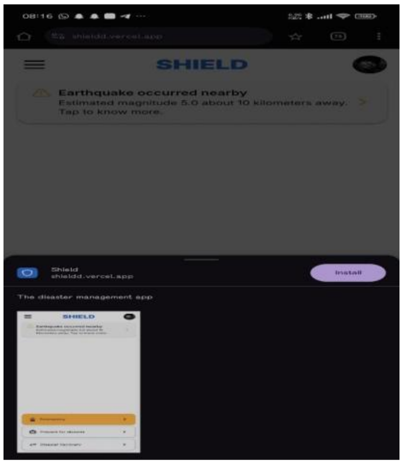

Figure 4: Installation Prompt

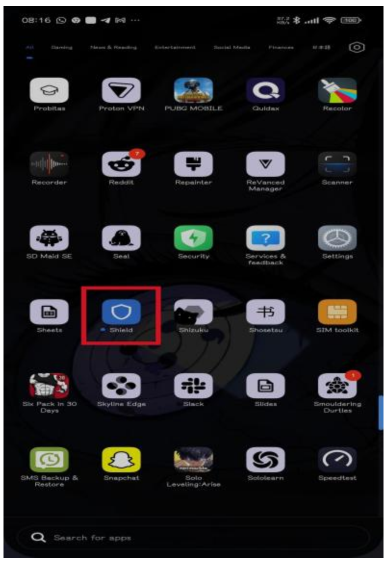

Figure 5: App installed as a PWA

Progressive Web App User Interface and Experience
Once the app has been installed as a PWA, the user can subsequently launch the app from their devices launcher just like a regular app. Whenever a user launches the app, they are greeted with a splash screen and subsequently navigated to the landing page.

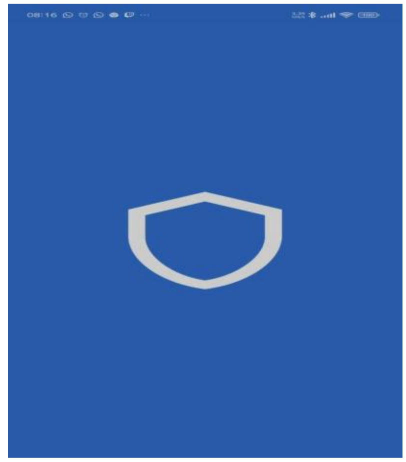

Figure 6: PWA splash screen

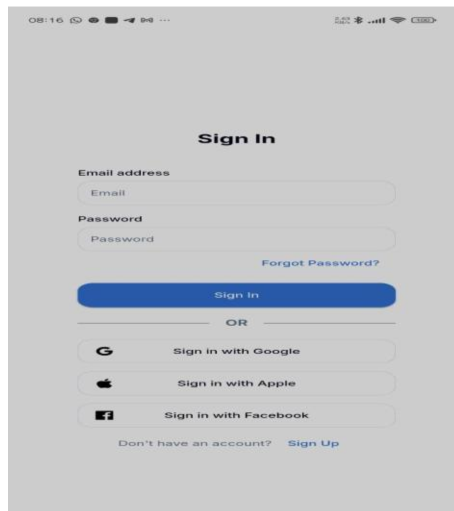

Figure 7: Sign in page

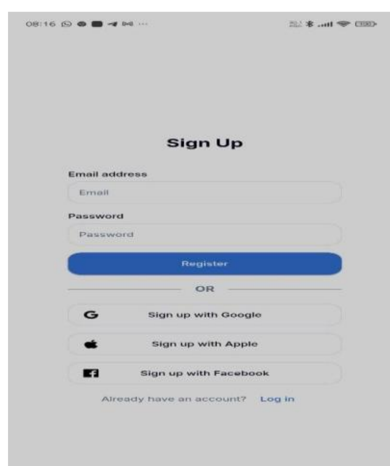

Figure 8: Register Page

Figure 9: PWA Landing Page

Figure 10: Disaster Information Page

Figure 11: Disaster Details Page

Figure 12: Evacuation Routes Page

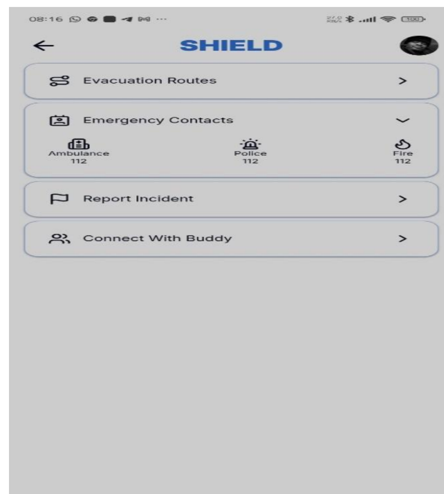

Figure 13: Emergency Contacts Section

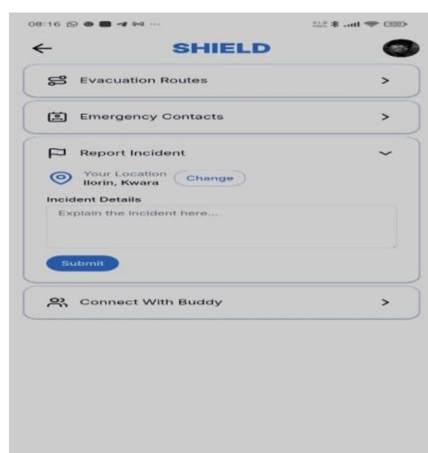

Figure 14: Report Incident Section

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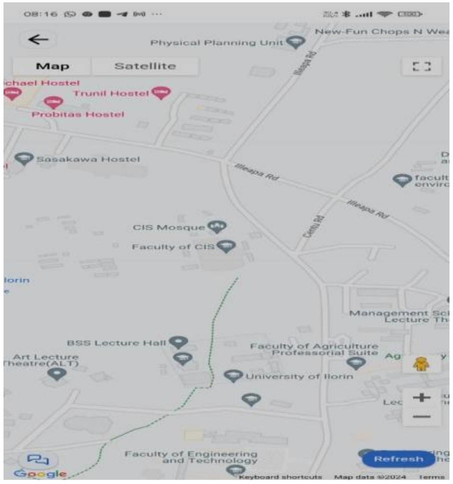

Figure 15: Connect with Buddy Page

Figure 16: Conversations/Buddies Page

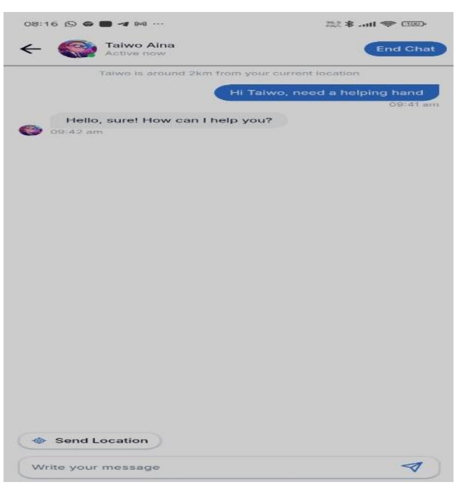

Figure 17: Chat/Conversation with Buddy Page

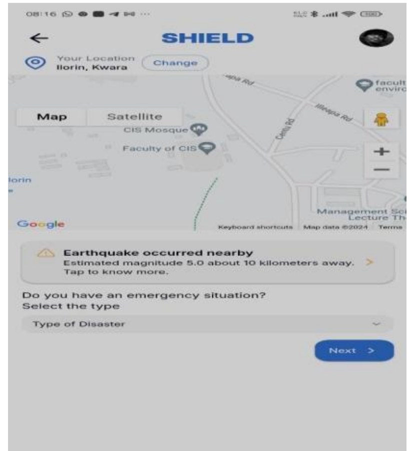

Figure 18: Emergency Page

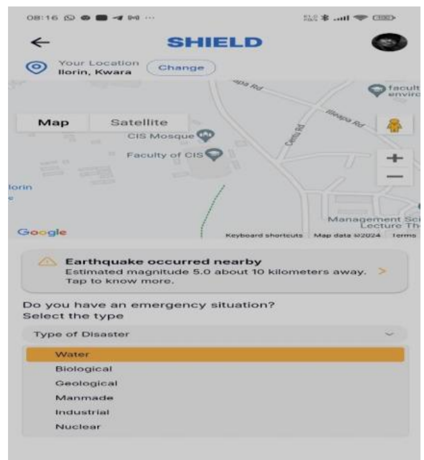

Figure 19: Emergency Type Selection Section

Figure 20: Emergency Type Selection Page

Figure 21: Emergency Type Details/Preparation Page

Figure 22: Disaster Preparation Type Page

Figure 23: Disaster Preparation Subtype Page

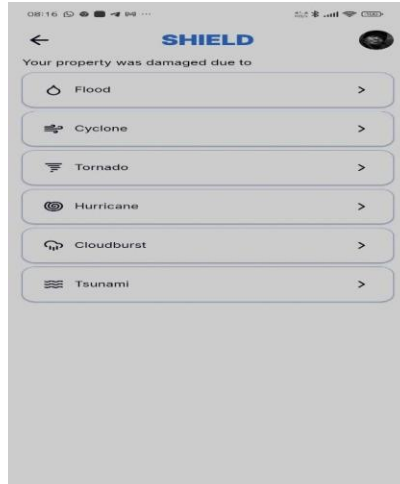

Figure 24: Disaster Recovery Damage Type Page

Figure 25: Disaster Recovery Service Request Page

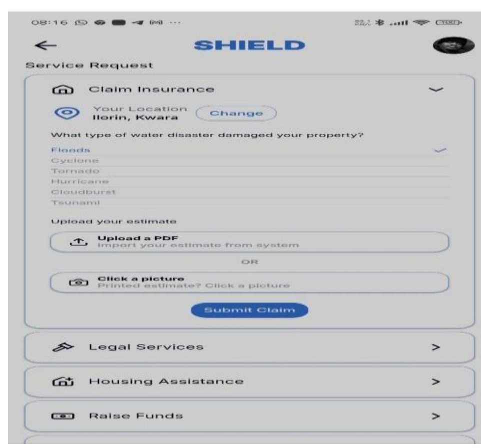

Figure 26: Disaster Recovery Insurance Claim Section

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DISCUSSION

The Progressive Web App (PWA) follows a structured user experience, starting with its Landing Page (Figure 3), which serves as the first point of interaction, providing an overview of its disaster response features. Users are then encouraged to install the app through the Installation Prompt (Figure 4), allowing them to add it to their home screen for easy access. Once installed, the app behaves like a native application, as shown in Figure 5 (App Installed as a PWA). When launched, the PWA Splash Screen (Figure 6) appears, displaying branding and animations while the app loads. To access its core functionalities, users are directed to the Sign-in Page (Figure 7), where they can enter their credentials, or proceed to the Register Page (Figure 8) to create a new account. After logging in, users land on the PWA Landing Page (Figure 9), which serves as the main dashboard, providing quick navigation to various disaster management tools and resources.

The app focuses on disaster response and preparedness by offering critical information and tools. The Disaster Information Page (Figure 10) provides real-time updates on ongoing disasters, while the Disaster Details Page (Figure 11) offers deeper insights, such as affected areas and severity levels. For evacuation planning, the Evacuation Routes Page (Figure 12) presents safe exit paths and shelters. Emergency communication is a key aspect, with the Emergency Contacts Section (Figure 13) listing important helplines and authorities. Users can actively contribute through the Report Incident Section (Figure 14), enabling them to report hazards or emergencies in their vicinity.

To enhance community-driven response efforts, the app includes a Connect with Buddy Page (Figure 15), allowing users to pair with others for mutual support. The Conversations/Buddies Page (Figure 16) displays a list of connected buddies, facilitating communication during disasters. Users can engage in real-time discussions through the Chat/Conversation with Buddy Page (Figure 17), ensuring seamless coordination. In case of an emergency, users can navigate to the Emergency Page (Figure 18), which provides immediate access to assistance and response options. The PWA also assists in disaster preparedness through structured guidance. The Emergency Type Selection Section (Figure 19) and Emergency Type Selection Page (Figure 20) help users identify different types of disasters they may face. Once selected, the Emergency Type Details/Preparation Page (Figure 21) provides tailored information on precautions and response strategies. Further categorization is available through the Disaster Preparation Type Page (Figure 22) and Disaster Preparation Subtype Page (Figure 23), which break down specific preparation measures based on disaster types. Post-disaster recovery is also addressed via the Disaster Recovery Damage Type Page (Figure 24), which guides users in assessing and reporting damage to facilitate aid distribution. This PWA integrates data analytics and real-time information sharing to improve disaster response and preparedness, offering a comprehensive digital tool to optimize resource allocation and enhance community resilience. Future enhancements could incorporate artificial intelligence for predictive analytics and automated decision-making in disaster management.

Conclusion

This project has outlined the design, execution, and effects of a Progressive Web App (PWA) specifically tailored to enhance resource allocation in disaster management scenarios. The PWA utilizes real-time data integration, adheres to user-centered design principles, and incorporates strong security protocols to equip disaster response teams with effective decision-making tools.

The PWA provides notable benefits compared to conventional resource allocation techniques. By harnessing real-time data from various sources, such as sensor readings, satellite imagery, and social media analytics, it offers a thorough understanding of the on-ground disaster conditions. This information is transformed into actionable insights through advanced data analysis and visualization tools, allowing responders to pinpoint areas with the most urgent needs and allocate resources effectively.

The user interface of the PWA emphasizes clarity, usability, and accessibility, accommodating a wide array of users who operate under the stress of disaster response. Its offline capabilities guarantee access to essential information even in regions with limited or absent internet connectivity. Furthermore, the inclusion of multilingual support enhances communication among international disaster response teams.

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