Universidade de Aveiro
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SPLASH

Strategic Prevention and Lifeguard Alert Safety Hub

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Relatório de projeto apresentada no âmbito da unidade curricular de Projeto em Engenharia de Computadores e Informática da Universidade de Aveiro, condição necessária para a obtenção do grau de Licenciado em Engenharia de Computadores e Informática, realizada sob a orientação científica do Professor Doutor Samuel de Sousa Silva, Professor auxiliar do Departamento de Eletrónica, Telecomunicações e Informática da Universidade de Aveiro, do Doutor Bernardo José Santos Marques, Professor auxiliar do Departamento de Eletrónica, Telecomunicações e Informática.

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palavras-chave

Segurança, Praia, Nadador-Salvador, Prevenção, Tecnologia.

resumo

O projeto *Strategic Prevention and Lifeguard Alert Safety Hub* (SPLASH) é uma prova de conceito destinada a melhorar a segurança e a gestão das praias portuguesas.A iniciativa centra-se em três eixos fundamentais: a gestão integrada das equipas e incidentes, o suporte direto ao trabalho dos nadadores-salvadores e a proteção dos banhistas. Com milhares de turistas a visitar as praias todos os anos, garantir que os nadadores-salvadores consigam desempenhar as suas funções de forma eficaz é essencial. O aumento do volume de visitantes traz novos desafios à vigilância e à prevenção de acidentes, tornando prioritária a adoção de soluções tecnológicas inovadoras que promovam a segurança e a reputação do país como destino turístico seguro.

O objetivo principal do SPLASH é o desenvolvimento de uma web app que apoie diretamente os nadadores-salvadores, disponibilizando um mapa interativo das praias, registo de ocorrências e ferramentas para a gestão eficiente das equipas. A solução visa melhorar a comunicação, a coordenação e a tomada de decisão por parte dos responsáveis pela segurança balnear.

A prova de conceito revelou-se promissora do ponto de vista da sua viabilidade técnica e operacional, apresentando bons resultados nos testes realizados. Estes dados reforçam o potencial da solução proposta para apoiar a gestão costeira e a segurança nas praias portuguesas.

keywords Safety, Beach, Lifeguard, Prevention, Technology.

abstract The *Strategic Prevention and Lifeguard Alert Safety Hub* (SPLASH) project is a proof of concept designed to improve the safety and management of Portuguese beaches. The initiative focuses on three main pillars: integrated management of teams and incidents, direct support for lifeguards' daily tasks, and protection of beach-goers. With thousands of tourists visiting the beaches each year, ensuring that lifeguards can perform their duties effectively is crucial. The growing number of visitors brings new challenges to surveillance and accident prevention, making it essential to adopt innovative technological solutions that enhance safety and support the country's reputation as a secure tourist destination.

SPLASH's main goal is the development of a web application that directly supports lifeguards by providing an interactive beach map, incident reporting features, and tools for efficient team management. The solution aims to improve communication, coordination, and decision-making among coastal safety authorities.

The proof of concept has shown promising results in terms of technical and operational feasibility, with positive outcomes from the tests conducted. These findings highlight the potential of the proposed solution to support coastal management and enhance safety on Portuguese beaches.

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Glossário

UA	Universidade de Aveiro
PECI	Projeto em Engenharia de Computadores e Informática
ECI	Engenharia de Computadores e Informática
SPLASH	Strategic Prevention and Lifeguard Alert Safety Hub
APA	Agência Portuguesa do Ambiente
AMN	Autoridade Marítima Nacional
UX	User Experience
SUS	System Usability Scale
DBMS	Database Management System
ERD	Entity Relationship Diagram
HTA	Hierarchical Task Analysis
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
SPI	Serial Peripheral Interface
I²C	Inter-Integrated Circuit
UBX	u-blox Binary Protocol
GATT	Generic Attribute Profile
BLE	Bluetooth Low Energy
GPS	Global Positioning System
FreeRTOS	Free Real-Time Operating System
PPS	Pulse Per Second
CPU	Central Processing Unit
AES-128/256	Advanced Encryption Standard (FIPS PUB 197)
SHA	Secure Hash Algorithm (FIPS PUB 180-4)
RSA	Rivest–Shamir–Adleman
HMAC	Hash-Based Message Authentication Code
Hz	Hertz
MHz	Megahertz
GHz	Gigahertz
ESP-IDF	Espressif IoT Development Framework
SoC	System-on-a-Chip
NMEA	National Marine Electronics Association
GGA	Global Positioning System Fix Data (NMEA sentence)
RMC	Recommended Minimum Navigation Information (NMEA sentence)
API	Application Programming Interface
GAP	Generic Access Profile

CHAPTER 1

Project Overview

1.1 Introduction

Beaches are universally popular destinations, and the number of tourists seeking coastal experiences continues to rise. Portugal, known for its favourable climate and extensive coastline, has become a prime location for this growing trend. As a result, lifeguards are under increasing pressure to manage larger crowds, which can compromise their ability to respond effectively to emergencies and heighten the risks faced by beachgoers.

The SPLASH project is a proof of concept developed in response to these challenges. It proposes a preventive and technological approach to support beach safety and management in real time. By leveraging digital tools, SPLASH aims to assist lifeguards in performing their duties more effectively, while also promoting safer behaviours among the public.

This initiative contributes to the modernization of coastal safety practices, helping to safeguard human lives and reinforcing Portugal's reputation as a global benchmark in beach sustainability and safety.

This chapter outlines the project's **context**, **challenges**, **objectives**, **boundaries**, and **expected outcomes**, providing a comprehensive overview of its scope and relevance.

1.2 Context

This project, focused on hazard signalling, team coordination, and preventive safety, was developed at the Universidade de Aveiro (UA) as part of the Projeto em Engenharia de Computadores e Informática (PECI) course, marking the final stage of the bachelor's degree in Engenharia de Computadores e Informática (ECI). It was carried out by a team of six students who independently selected the topic, demonstrating both initiative and a strong interest in addressing real-world issues related to beach safety.

The work reflects the application of knowledge acquired throughout the degree in a practical context. With beach safety becoming an increasing concern, particularly during summer when lifeguard staffing is often limited, this project explores how smart systems and digital tools can enhance lifeguard operations and contribute to safer beach environments.

1.3 Challenges

The project aims to address several key challenges faced by lifeguards:

- Inefficient communication, scheduling, and resource allocation.
- Difficulty monitoring and managing large beach areas.
- Delayed detection and signalling of hazards and dangerous conditions.
- Increasing climate variability impacting beach safety.

1.4 Objectives

The primary objective of SPLASH is to develop a technological solution that supports the various dimensions of a lifeguard's responsibilities, through preventive strategies and digital tools. The specific objectives include:

- **Support human resource management:** Provide tools for supervisors to assign lifeguards to posts, manage weekly schedules, and monitor real-time duty status, thus improving operational efficiency.
- **Enable hazard reporting and tracking:** Allow lifeguards to report hazards using an interactive map, with logs per beach to support data-driven preventive action.
- **Provide weather information:** Integrate real-time weather data and forecasts to support safety decisions under changing conditions.
- **Inform the public:** Offer a simplified version of the system to beach-goers, showing up-to-date conditions and hazard alerts, promoting awareness, and reducing unnecessary interactions with lifeguards.
- **Enable device integration within a single ecosystem:** Facilitate seamless onboarding and management of external IoT devices in the SPLASH ecosystem, allowing real-time data streams such as location or environmental detection to enrich situational awareness and improve prevention and response capabilities benefiting lifeguards and bathers.

1.5 Boundaries

As a proof of concept, the SPLASH system focuses on supporting lifeguards, improving communication of beach hazards, and informing beach-goers. The system is designed to:

- Be deployed in beach settings with a focus on coastal safety.
- Assist lifeguards in their operational duties.
- Facilitate hazard detection, reporting, and information sharing.
- Serve multiple stakeholders, including supervisors, tourists, and beach-related businesses.

The core functionalities of the system include:

- Interactive map with real-time data.
- Hazard reporting and alert mechanisms.
- Historical beach metrics and incident logs.

- Information on available beach amenities.

The system is intended for the following user groups:

- **Lifeguards:** Both supervisors and general staff.
- **Beach-goers:** Individuals visiting for leisure.
- **Beach business owners:** Surf schools, food stalls, rentals, and related services.

1.6 Expected Outcomes

Based on the objectives and system boundaries defined above, this subsection describes the tangible benefits that the SPLASH proof of concept will provide to its primary stakeholders.

- **For lifeguards:** A digital platform to streamline human resource management, allowing assignment to posts, scheduling organization, and real-time tracking of on-duty staff. The system will also support hazard reporting, store incident histories, and integrate weather forecasts to enhance situational awareness.
- **For beach-goers:** A simplified public interface providing access to current weather conditions and hazard alerts for each beach. This promotes safer decision making, encourages responsible behaviour, and raises awareness of potential risks.

CHAPTER 2

Team Coordination and Project Management

Effective communication is the cornerstone of successful software development, especially in multidisciplinary teams. A structured **Team Communication Plan** ensures that all members remain aligned, informed, and coordinated toward shared objectives.

This chapter presents the communication strategies and project management practices adopted throughout SPLASH's development. These include the selection of collaboration tools, scheduling methodologies, team structure, and risk mitigation strategies. Together, they form a robust framework to support the project's lifecycle—from initial planning to final deployment.

2.1 Communication Tools and Platforms

- **GitHub:** Used for version control and collaborative development. It serves as the central repository for source code, issue tracking, and code review.
- **OneDrive & Overleaf:** Used for collaborative documentation. These tools allow for real-time editing and maintain a consistent version history of all written deliverables.
- **Jira:** Employed for agile project management, sprint planning, and milestone tracking. Provides an overview of tasks and responsibilities.
- **Discord:** Chosen for synchronous communication, including voice calls, video meetings, and chat. Enables both scheduled and informal interactions.

2.2 Schedule and Meetings

Excel was used to coordinate individual availabilities and to schedule regular team meetings and supervisor check-ins. This tool enabled effective time management and ensured team-wide alignment, as illustrated in Figure **??**.

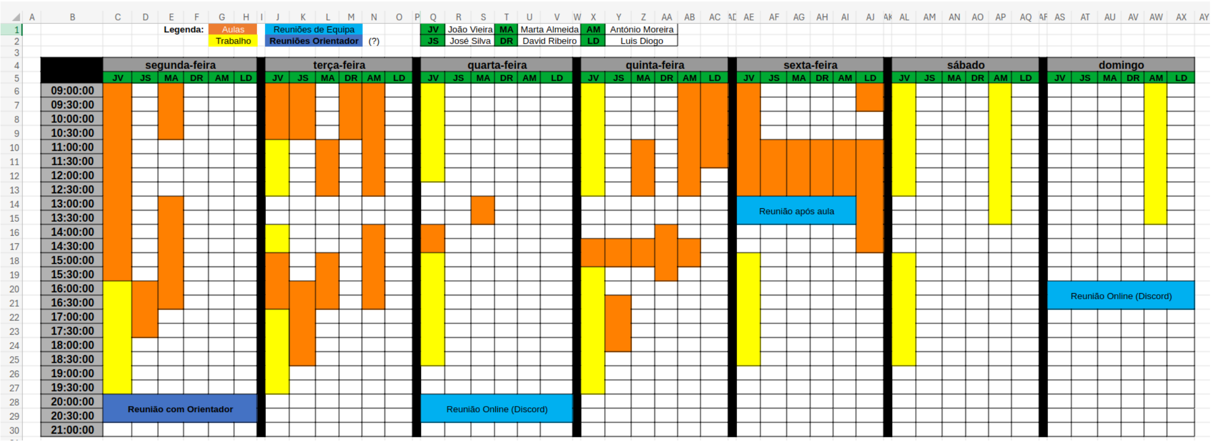


Figure 2.1: Team schedule and meeting planner implemented in Excel, showing member availability, scheduled meetings, and project milestones for the first semester

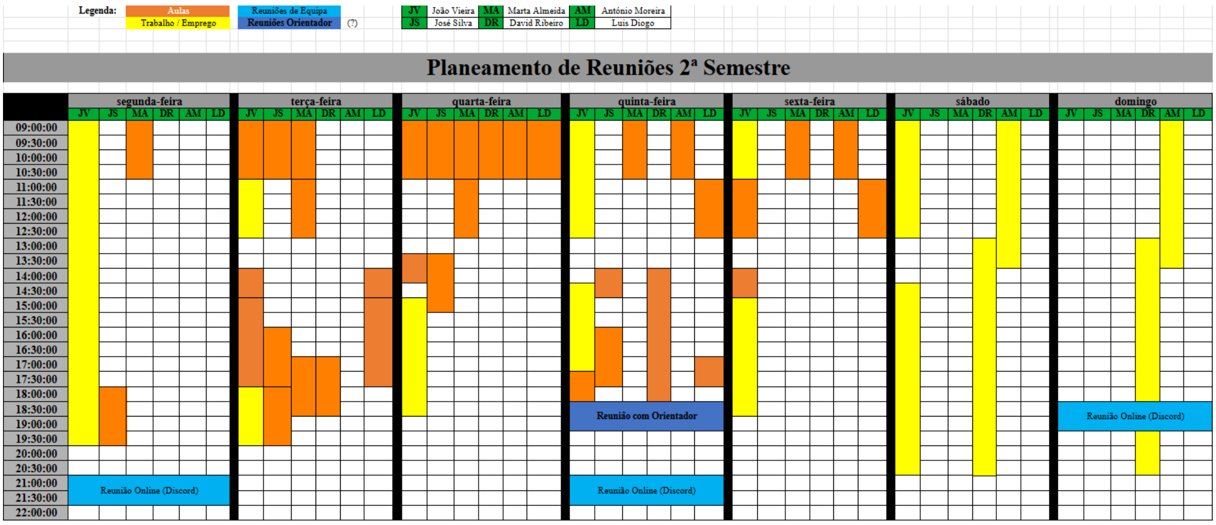


Figure 2.2: Team schedule and meeting planner implemented in Excel, showing member availability, scheduled meetings, and project milestones for the second semester

2.3 Team Structure and Roles

Effective project execution relies heavily on a well-defined team structure with clear responsibilities. This section outlines the adopted framework, designed to optimize workflow and ensure comprehensive coverage of project needs.

2.3.1 SCRUM Master

João Vieira was designated as the *SCRUM Master*, responsible for:

- Facilitating the SCRUM process
- Ensuring adherence to SCRUM principles
- Removing obstacles to team progress
- Fostering a culture of continuous improvement

2.3.2 Sub-teams

To leverage team strengths, members were grouped into three specialized sub-teams:

Frontend Development Team

- **Team Leader:** José Silva
- **Members:** José Silva & Antonio Moreira
- **Responsibilities:**
  - UI design and implementation
  - Responsive layout creation
  - UX optimization
  - Integration with backend APIs

Backend Development Team

- **Team Leader:** João Vieira
- **Members:** João Vieira
- **Responsibilities:**
  - Server-side logic and database design
  - API development
  - Performance optimization

Data Team

- **Team Leader:** Marta Almeida
- **Members:** Marta Almeida & David Ribeiro
- **Responsibilities:**
  - Validation and processing of quiz results submitted by lifeguards
  - Planning, execution, and storage of user testing data
  - Providing technical support to other teams regarding data-related matters

Hardware Development Team

- **Team Leader:** Luis Diogo
- **Members:** Luis Diogo
- **Responsibilities:**
  - Develop embedded firmware
  - Integrating devices with the SPLASH ecosystem

2.4 Risk Analysis and Mitigation Strategies

The implementation of SPLASH involves technological, environmental, and human-related risks. These must be addressed to ensure system reliability and user safety.

- **Hardware and Connectivity Failures:** Devices such as GPS wristbands or communication tablets may malfunction or lose connectivity. This can be mitigated through pre-deployment testing, scheduled maintenance, and having redundant devices available.
- **Environmental Conditions:** Weather-related events (e.g., high winds, salt exposure) may affect equipment performance. Selecting durable, weather-resistant hardware and establishing operational contingency protocols can reduce these risks.
- **Human Error and Technological Adoption:** Some users may struggle with adapting to new tools. This risk is mitigated by ensuring the interface remains user-friendly and providing training sessions to lifeguards and supervisors.

2.5 Conclusion

In summary, the project's success depended not only on technical development but also on structured communication and clearly defined responsibilities. The use of collaborative tools, agile methodologies, and proactive risk management contributed significantly to the team's cohesion and overall project quality.

CHAPTER 3

State of the Art and Market Analysis

This chapter merges the current state of technology in beach safety with a market analysis, focusing on the SPLASH project and its potential impact.

3.1 Related Projects Implemented in Portugal

Several digital initiatives have been implemented in Portugal to improve beach safety, environmental monitoring, and user experience. Below are some notable examples that serve as inspiration or complementary efforts to the SPLASH project.

3.1.1 MEO Beachcam

MEO Beachcam is a digital platform that provides real-time information about the beaches of mainland Portugal.

The platform provides around-the-clock video transmission of the beaches through a network of cameras. In addition to the live video feeds, MEO Beachcam provides extensive meteorological data, including: weather conditions, temperature, wind strength and direction, sea state, and UV index. In addition to being accessible on the platform, the aforementioned data is also available to security forces and rescue services for monitoring and emergency response. In addition to oceanographic buoys and weather stations for data collection, the platform also employs artificial intelligence to analyze wave patterns and better predict weather conditions.

The project is committed to expand and enhance its coastal monitoring infrastructure. Future plans for development include the expansion of the existing camera network and the deployment of drone technology to capture aerial imagery, all of which while seeking to increase the number of monitored beaches throughout mainland Portugal.

3.1.2 Info Praia

Info Praia is a mobile app developed by the Agência Portuguesa do Ambiente (APA) with the purpose of providing actualized information during the bathing season on many of the beaches of Portugal[1].

It provides information on beach occupation and occupation prediction based on data from registered homologue days. The data used for the daily weather forecast is provided by the Instituto Português do Mar e da Atmosfera, I.P (IPMA, I.P). The data on the tides are provided by the Instituto Hidrográfico[2]. The water quality is monitored by the APA at least four times for each bathing season to verify bathing suitability and display suitability in the app. Furthermore, is displayed by the app real-time video transmitted by the MEO Beachcam platform analyzed previously.

3.1.3 Praia 5G

Praia 5G is a joint initiative between NOS and Almada city council to launch the first 5G beach in Portugal. This project has the objective of demonstrating how the 5G network technology, artificial intelligence and video analysis can transform the security and management of beaches[3].

The beach was equipped with a 5G network to support all the functionalities implemented. One of the functionalities is the automated monitorization of persons, objects and vessels. This beaches allowed the demonstration of the detection of risk situations, automated alerts for the responsible entities and it uses artificial vision cameras in vigilance towers that process in real time the images through machine learning algorithms allowing immediate response in emergency situations[3]. Another functionality is the monitorization and management of the beach occupation which includes automatic counting the number of visitors and their respective entry and exit times and the capacity to estimate the concentration of people per area of the beach[3], [4]. Lastly, the management of residues is elaborated by the readings of sensors that measure the garbage bins capacity[4].

This project has the future perspective of implementing functionalities such as drowning detection, children and lost objects localization through artificial intelligence. Also, it is intended to use drones for real time data of weather conditions and to increase the sustainability expand the system to detect garbage in the sea with the possibility of the use of cleaning robots[4].

3.2 Technologies

3.2.1 React

React is a JavaScript library used for building user interfaces, particularly for single-page applications. Its core design is centered on the concept of reusable components, which are isolated, self-contained pieces of UI that can be composed to build complex interfaces. A key characteristic of React is its use of a Virtual DOM. This feature improves application performance by creating an in-memory representation of the UI, calculating the minimal changes needed, and then updating the real DOM efficiently. The library employs JSX, a syntax extension that allows developers to write HTML-like code within JavaScript, which improves code readability and maintainability. React also enforces a unidirectional data flow, where data is passed down from parent to child components, making application state more predictable and easier to debug. For this project, the React frontend was developed using modern tooling, including the Vite build tool for a fast development server and optimized production bundles. The application's functionality was extended with specific libraries, including react-router for client-side navigation and Leaflet with react-leaflet to render the interactive maps required for location tracking. React offers several advantages for frontend development. Its component-based architecture inherently promotes code reuse, which can significantly speed up the development process. The use of a Virtual DOM generally results in high rendering performance, leading to a responsive user experience, especially in applications with dynamic data. Furthermore, React is supported by a massive and active community, which ensures a vast ecosystem of third-party libraries, tools, and extensive documentation. There are also trade-offs to consider when using React. As it is fundamentally a library for the 'view' layer, it does not include built-in solutions for more complex application concerns like global state management or client-side routing. Consequently, projects often require integrating and managing multiple auxiliary libraries, which can increase complexity and maintenance overhead. This dependency on a wider ecosystem can present a learning curve for developers new to the platform. React was selected for this project because its modular architecture and performance characteristics were well-suited to the development of a high-performance, interactive user interface. The ability to create reusable components and leverage a rich ecosystem of specialized libraries, such as those for mapping and routing, was critical for delivering the required features within the project's timeline. Although a reliance on external libraries was a known consideration, the development speed and robust community support offered by the React ecosystem were deemed to outweigh the potential complexities.

3.2.2 Web Bluetooth API

This section presents the technologies employed for this project. The Web Bluetooth API allows a web page running JavaScript to act as a Bluetooth Low Energy (BLE) Central device, facilitating direct discovery and communication with nearby BLE peripherals without requiring a native companion application. While this approach significantly streamlines integration of the proof-of-concept wearable, the API remains in an experimental stage under active development by the Web Bluetooth Community Group and is not yet a W3C standard. For security, browsers support it only in secure contexts over HTTPS, and any device-request function must be initiated through a genuine user gesture such as a click or touch event, preventing unwanted or malicious device prompts. Current compatibility extends across Chromium-based browsers including Chrome on desktop and Android, Edge, and Opera while key browsers like Firefox and Safari remain without support. Given its draft status and the associated security and compatibility limitations, the API is best suited for prototyping or controlled deployments rather than widespread production release. Nevertheless, SPLASH leverages the browser's native BLE functionality to connect directly to the bracelet hardware without native code, accelerating development and validating the SPLASH ecosystem vision with minimal complexity[5], [6].

3.2.3 C# and ASP.NET Core

ASP .NET Core, together with the C# language, constitutes a lightweight, modular, and cross-platform framework for building high-performance RESTful APIs. It runs reliably on Windows, Linux, and macOS thanks to the Kestrel web server and the efficient Central Processing Unit (CPU). The middleware pipeline enables precise configuration of HTTP request handling, and built-in dependency injection supports clean architectural patterns without requiring additional libraries. Asynchronous programming with async/await ensures non-blocking I/O operations, significantly enhancing scalability under concurrent workloads. Benchmarks consistently demonstrate that .NET 6 and later versions deliver throughput on par with or exceeding Node.js implementations—such as completing one million requests in approximately six seconds compared to 47 seconds on typical Express.js setups—while maintaining developer productivity. The mature ecosystem including Entity Framework Core for ORM, Swagger for API documentation, and integrated health-check tooling—supports rapid development cycles, and C#'s strong static typing enhances code safety by detecting errors at compile time. Although the managed runtime introduces marginally greater memory overhead compared with native frameworks, that cost is offset by improved developer efficiency and maintainability. The decision to implement the API using C# and ASP .NET Core enabled a robust, maintainable, and scalable backend, and Visual Studio's seamless Azure integration simplified deployment and lifecycle management through managed pipelines and services.

3.2.4 PostgreSQL

PostgreSQL offers a powerful relational database engine that ensures full ACID compliance through multiversion concurrency control, maintaining data consistency even after unexpected shutdowns. Its support for advanced data types such as JSONB and arrays equips it to handle complex, document-like structures within a single schema, while the PostGIS extension enables comprehensive spatial querying and indexing. High availability is provided through both streaming and logical replication, and tools like Patroni can be employed to automate failover and clustering with minimal runtime intervention. PostgreSQL has a well-documented reputation for reliability in mission-critical settings, with deployments that have sustained 24/7 operation without experiencing data loss or corruption. Its sophisticated query planner and execution engine deliver robust performance across a range of workloads, from high-volume OLTP tasks to computationally heavy analytical queries. Although achieving peak performance may require tuning parameters such as autovacuum thresholds and work memory, and administrators moving into enterprise-scale environments may encounter a steep learning curve, these trade-offs are offset by PostgreSQL's unwavering data integrity guarantees, scalable architecture, and zero licensing costs. The decision to adopt PostgreSQL provided a dependable and cost-effective foundation capable of managing diverse datasets—including user profiles, session histories, access permissions, and geographic location logs.

3.2.5 Microsoft Azure

Azure delivers both Platform-as-a-Service (PaaS) and Infrastructure-as-a-Service (IaaS) capabilities, supporting App Services, managed PostgreSQL instances, serverless compute via Functions, virtual machines, and storage services. The platform also offers built-in continuous integration and deployment through Azure DevOps or GitHub Actions pipelines, coupled with comprehensive monitoring and diagnostics via Application Insights and Log Analytics. These features enable automatic global scalability, load balancing, patching, and infrastructure maintenance—allowing developers to prioritise application logic over operational tasks—while service-level agreements and regional data centre redundancy provide enterprise-grade availability. Despite its benefits, Azure's initial configuration demands careful design: defining virtual networks, access policies, and security settings introduces complexity, and the deep integration with proprietary services increases the risk of vendor lock-in, making migration more difficult and costly in the future. Furthermore, while Azure's pay-as-you-go model enables flexible spending, costs can grow exponentially without constant monitoring and optimisation. Notwithstanding these challenges, Azure provided a secure and scalable hosting environment for the SPLASH web application. Its seamless integration with .NET and Visual Studio simplified deployment processes, and managed services allowed rapid provisioning of production-quality infrastructure through CI/CD pipelines and monitoring tools, ensuring high availability and maintainability of the backend stack.

3.2.6 ESP32-S3-WROOM-1

The ESP32-S3-WROOM-1 module integrates an Xtensa® dual-core 32-bit LX7 microprocessor that operates at up to 240 **MHz!** (**MHz!**), delivering sufficient performance to manage concurrent tasks, such as BLE communication and Global Positioning System (GPS) data parsing. This System-on-a-Chip (SoC) includes an ultra-low-power co-processor that can monitor peripherals while the main cores are powered down, enabling extremely power-efficient operation. Native support for 2.4 **GHz!** (**GHz!**) Wi-Fi (IEEE 802.11 b/g/n) and Bluetooth 5 LE enhances communication flexibility and simplifies printed circuit board design. Peripheral interfaces such as Universal Asynchronous Receiver/Transmitter (UART), Inter-Integrated Circuit (I^2C), Serial Peripheral Interface (SPI), PWM, ADC, and a full-speed Universal Serial Bus (USB) 2.0 OTG interface further support rich hardware integration. Security is addressed at the hardware level through secure boot, flash encryption, and integrated cryptographic accelerators for Advanced Encryption Standard (FIPS PUB 197) (AES-128/256), Secure Hash Algorithm (FIPS PUB 180-4) (SHA), Rivest–Shamir–Adleman (RSA), and Hash-Based Message Authentication Code (HMAC), thereby ensuring firmware integrity and preventing tampering. These hardware features are complemented by the Espressif IoT Development Framework (ESP-IDF), which is based on Free Real-Time Operating System (FreeRTOS) and includes comprehensive libraries, drivers, and examples that accelerate development. The module's compact dimensions of $18 \times 25.5 \times 3.1$ mm suit wearable applications. However, this concentration of performance and features increases complexity: configuring low-power modes, peripheral multiplexing, and secure boot procedures requires a thorough understanding of embedded systems, and the rich feature set entails careful power management to maintain acceptable battery life. In the context of this project, the use of the ESP32-S3-WROOM-1 provided a mature and powerful foundation for the wearable device, and its support within ESP-IDF significantly simplified firmware development and debugging workflows[7].

3.2.7 u-blox NEO-6M

The u-blox NEO-6M GPS module delivers horizontal position accuracy of approximately 2.5 m, ensuring sufficient spatial resolution for wearable localization. It achieves tracking sensitivity down to –161 dBm, enabling reliable satellite acquisition and maintenance even under weak-signal conditions. Time synchronization relies on a Pulse Per Second (PPS) output with a root-mean-square accuracy of 30 ns, which supports precise timestamping of location data. The module's navigation update rate reaches up to 5 Gigahertz (GHz), balancing responsiveness with power consumption for tracking typical human movement. Communication occurs primarily over UART, though the NEO-6M also offers SPI, I^2C and USB interfaces for integration flexibility. Initial fixes emerge after a cold start of around 27 s, reducing delay for first-time position acquisition. Packaged in a compact $16.0 \times 12.2 \times 2.4$ mm LCC, the module suits the size constraints of a wearable bracelet. All NEO-6 modules are built on GPS chips qualified to the AEC-Q100 automotive standard and comply with RoHS directives, ensuring both reliability in harsh environments and regulatory alignment. Despite these strengths, the maximum 5 GHz update rate may limit very high-speed tracking scenarios, and cold-start durations near half a minute can delay initial lock; furthermore, achieving peak performance requires appropriate antenna selection and configuration. The adoption of the NEO-6M provided a cost-effective, rugged, and highly accurate foundation for managing user location profiles, session logs, permissions, and geolocation records within the SPLASH ecosystem[8], [9].

3.2.8 Bluetooth Low Energy (BLE)

This section presents the technologies employed for this project. BLE defines a wireless standard optimised for intermittent, low-power data exchange at physical-layer bit rates of 125 kbps, 500 kbps, 1 Mbps and 2 Mbps and supports both connection-oriented and broadcast communication modes. The protocol employs adaptive frequency hopping to mitigate interference in the crowded 2.4 **GHz!** ISM band by dynamically excluding poor-performing channels based on real-time environmental measurements. AES-128/256-CCM encryption and message authentication protect data integrity and privacy during transmission, meeting modern security requirements for sensitive information. For ultra-low-power scenarios, BLE supports subrated connections that maintain persistent but extremely low-duty-cycle links, minimising energy draw outside of active data-transfer events. Because battery conservation is paramount in wearable devices, BLE radios consume only a few milliamperes during active packet exchanges and drop to microampere-level sleep currents when idle. The high-speed LE 2M PHY can sustain application-level throughputs up to 1.4 **Mbps!** (**Mbps!**)—adequate for periodic location updates and sensor telemetry—while legacy LE 1M and coded PHYs trade peak speed for extended range. BLE's half-duplex radio architecture requires that transmission and reception cannot occur simultaneously, necessitating scheduling strategies for bidirectional data flows. Furthermore, the link-layer state machine's complexity—driven by advanced quality-of-service, privacy and mesh-networking features—can extend development effort when custom profiles or non-standard workflows are needed. Typical operational range spans 30–50 m in unobstructed environments, satisfying most wearable scenarios, although actual distance varies with antenna design and environmental conditions. BLE's combination of ultra-low active and sleep currents, robust security framework, adaptive interference management and flexible PHY options for both throughput and range makes it ideally suited for the SPLASH bracelet's requirement to relay periodic location and status information over extended battery lifetimes with minimal additional development overhead[10].

3.2.9 Apache Mynewt NimBLE

Apache Mynewt NimBLE is a fully open-source BLE stack that provides both host and controller implementations under the Apache License 2.0. It implements the complete Bluetooth 5 specification, including L2CAP channels, ATT protocols, GAP for device discovery and advertising, and Generic Attribute Profile (GATT) for service and characteristic operations. The stack supports extended and periodic advertising with multiple advertising sets, giving engineers control over payload contents, intervals and physical-layer parameters. Native Bluetooth Mesh support—including PB-GATT and PB-ADV provisioning, relay functionality and GATT Proxy—enables scalable many-to-many topologies that use managed-flood algorithms for efficient low-power relaying. Security is provided end-to-end via bonding procedures, AES-128/256-CCM link-layer encryption and integrity checks to prevent tampering. Thanks to its modular design and careful resource management, NimBLE operates with a RAM footprint as small as 8–16 KB and flash usage under 100 KB, making it ideal for constrained microcontrollers. Fine-grained power control follows from the ability to tune clock sources and advertising parameters to minimise radio-on time, extending battery life in energy-sensitive applications. Integration with the ESP-IDF framework on the ESP32 platform delivers a native host port, VHCI interface and FreeRTOS compatibility, reducing porting effort and accelerating development cycles. Despite these strengths, achieving optimal energy savings requires careful calibration of clock-settle durations and advertisement intervals, which can lengthen development and testing time, and enabling mesh or address-privacy features without precise configuration can inadvertently increase radio duty cycles and diminish autonomy. By combining a compact footprint, comprehensive GAP/GATT APIs, robust security services and exhaustive power-tuning options within an ESP-IDF–integrated stack, Apache Mynewt NimBLE delivers engineers precise control over BLE operations and broad smartphone compatibility, supporting modern IoT and wearable applications[11], [12].

3.3 Market Analysis and Business Evaluation

This comprehensive analysis highlights the market potential for SPLASH in improving beach safety while addressing existing gaps in current solutions.

3.3.1 Market Overview

1. **Demand for Beach Safety Solutions:** The rise in tourism necessitates effective safety measures to protect beachgoers, driving demand for innovative solutions.
2. **Unique Value Proposition:** SPLASH aims to unify various applications and stakeholder needs into a single platform, enhancing beach safety management.
3. **Global Expansion Potential:** Initially targeting Portuguese beaches, SPLASH's scalability allows for future international market entry.
4. **Monetization Strategies:** The business model includes premium accounts for local businesses and a licensing model for lifeguard organizations, ensuring sustainable revenue streams.

3.3.2 Competitors Analysis

The competitive landscape includes established services and emerging technologies.

Current Technologies

- APA: Conducts water quality assessments and operates the *Beachcam* web app for live feeds of Portuguese beaches.
- Autoridade Marítima Nacional (AMN): Runs lifesaving stations and projects like *Project Seawatch* focused on surveillance in unmonitored areas.
- Info Praia App: Provides updates on water quality but lacks availability on major platforms.

Emerging Technologies

- AI-Based Riptide Detection Tools
- Smart Beach Initiatives
- Drone Surveillance Systems

SPLASH distinguishes itself by integrating these technologies into a cohesive platform focused on proactive rather than reactive safety measures.

3.4 Business Model Evaluation

SPLASH employs a multi-faceted business model addressing the needs of both beachgoers and lifeguard organizations:

- **Free Web Application for Users:** This approach encourages widespread adoption while collecting valuable user data.
- **Premium Listings for Businesses:** Local businesses can enhance visibility within the app, benefiting from increased traffic while supporting SPLASH financially.

- **Licensing for Lifeguards:** Affordable licensing options will be offered to lifeguard organizations once established, providing access to advanced features tailored to their needs.

This model fosters user engagement and creates diverse revenue streams that support long-term growth.

3.5 Marketing Strategy Assessment

To penetrate the market effectively, SPLASH can implement a robust marketing strategy:

- **Partnerships with Authorities:** Collaborating with local governments and tourism boards will promote SPLASH as an essential tool for beach safety, and give SPLASH the needed credibility in the eyes of the general public.
- **Social Media Engagement:** Creating content that emphasizes beach safety and showcases SPLASH's unique features will build brand awareness.
- **Industry Participation:** Attending conferences focused on coastal management will facilitate networking opportunities and demonstrate SPLASH's capabilities.

Note: *Key Performance Indicators (KPIs) will be utilized to measure user adoption rates, engagement metrics, and feedback.*

3.6 SWOT Analysis

The following SWOT analysis provides insight into SPLASH's strategic position:

- **Strengths:**
  - Innovative technology integration.
  - Comprehensive approach to beach safety.
  - Potential positive impact on public health.
- **Weaknesses:**
  - Initial reliance on user adoption; user-centered development will mitigate resistance by tailoring solutions to user needs.
- **Opportunities:**
  - Expanding global tourism market.
  - Increasing focus on preventive safety measures.
  - Potential partnerships with stakeholders.
- **Threats:**
  - Regulatory challenges across jurisdictions.
  - Competition from established technologies.
  - Economic fluctuations impacting tourism spending.

CHAPTER 4

User-Centered Design

In software development and User Experience (UX) design, understanding the diverse array of individuals who interact with or are affected by a system is imperative, as this understanding forms the cornerstone to create solutions that not only function well but also are tailored and resonate deeply with their intended users.
This chapter undergoes a comprehensive exploration of stakeholders and personas, exploring into their motivations and the scenarios in which they operate. By identifying key stakeholders and developing detailed personas, we aim to create an accurate portrayal of our user base. This approach allows the development team to empathize with target audiences needs, anticipate their challenges, and design solutions that truly address their pain points.

4.1 Lifeguard Survey

With the objective of understanding the real-world context of lifeguard work, a survey was conducted with the Instituto de Socorro a Náufragos (ISN), which—under the legal regime for lifeguards established by Lei n.º 68/2014 (Artigo 40)[13]—is responsible for certifying all lifeguards in the country, as well as all academies, associations, equipment, and stores that sell said equipment. The ISN also plays an important role in educating and raising the public's awareness of the dangers inherent in beaches and pools, as well. The survey was sent directly to the ISN, who promptly distributed it among their lifeguards.

The survey was structured as follows.

- **Consent and Data Usage Notice**
- **Personal Information**
  - Age Range
  - Gender
  - Prior Field Experience

- **Field Related Questions**
  - What is your work environment? (Beach, pool, etc.)
  - What is a typical day of your life as a lifeguard?
  - What are your main responsibilities and tasks?
  - What kind of equipment and resources do you have available to carry out your job
  - Is there any equipment (or technology) you feel is missing or would like to have to better help you work?
  - Are there recurring frustrations at work? How do you handle them?
  - How does communication work between lifeguard team members?
  - Do you use any system or technology to keep in touch?
  - How is the organization of lifeguards structured? (i.e. vigilance areas, shifts, etc.)
  - If so, how is it managed?
  - What are the most common situations that require your attention?
  - What are some emergencies you have faced?
  - Can you describe the procedure for the case of a drowning?
  - How do you handle stress during emergencies?
  - Leave your suggestions and opinions.

4.1.1 Survey Results Overview

In total, the survey ended with 357 answers from the Portuguese lifeguards. While the open ended nature of the survey's questions was intentional, since the team had little to no knowledge of the field's requirements and necessities, this resulted in a sizeable amount of information to process. The method for analysis was mainly quantitative, by keeping a tally of each topic mentioned in an answer. This method ensured the most common and shared experiences to be highlighted, while not discarding any topic unique to specific people and their experiences and conditions.

Personal Information

In this section the lifeguards were asked their gender, age, years of experience, and what kind of station they work at. Despite being developed mainly for oceanic beaches, the survey did not exclude the other lifeguard's experiences.

The majority of respondents identified as male, accounting for 78% of the sample. Female respondents represented 21%, while 1% either identified as another gender or chose not to disclose their gender. This distribution reflects a predominantly male demographic among the surveyed lifeguards, which may be indicative of broader trends in the profession.

Regarding age, 48% of respondents were between 18 and 24 years old, representing the largest age group in the sample. A further 35% were aged between 25 and 34, followed by 13% aged between 35 and 45. Only 4% of participants were over 45 years old. This distribution suggests that the surveyed lifeguards are predominantly young adults, which aligns with the physically demanding nature of the profession.

In terms of professional experience, 47% of the respondents reported having between 1 and 3 years of experience as lifeguards. Another 25% had between 4 and 6 years, while 16% had between 7 and 10 years. The remaining 12% had over 10 years of experience.

Field Related Questions

1. ***What is your work environment?***

Respondents reported working across a variety of lifeguard settings. A total of 25% of participants indicated working at ocean beaches, 12% at river or lake beaches (inland waters), 29% in swimming pools, and 4% at water parks. This distribution reflects the diversity of operational environments in which lifeguards perform their duties, each with its own set of risks, procedures, and communication demands..

2. ***What is a typical day of your life as a lifeguard?***

A typical day for a lifeguard in Portugal is highly structured, long, and centered on vigilance. While routine and quiet for some, the need to stay alert is a shared experience. Most lifeguards perform consistent operational duties such as setting up the post, monitoring the beach, and engaging with bathers for preventive action.
There's a clear emphasis on team collaboration and effective communication, supported by widespread use of radios and binoculars, which will be further addressed in it's own question..

Figure 4.1: Number of mentions of each keyword in Question 2.

3. ***What are your main responsibilities and tasks?***

Portuguese lifeguards describe their role to be mainly rooted in prevention, constant vigilance, and public interaction. These seem to be their top concern, as they were reflected in most answers.

When prevention fails, however, first aid, verbal guidance and rescues are also recognized as essential. Other less mentioned duties are operational support (such as setting up posts, checking equipment, and preparing the area at the start and end of each shift). Reporting and documentation, as well as beach maintenance, were more scarcely brought up..

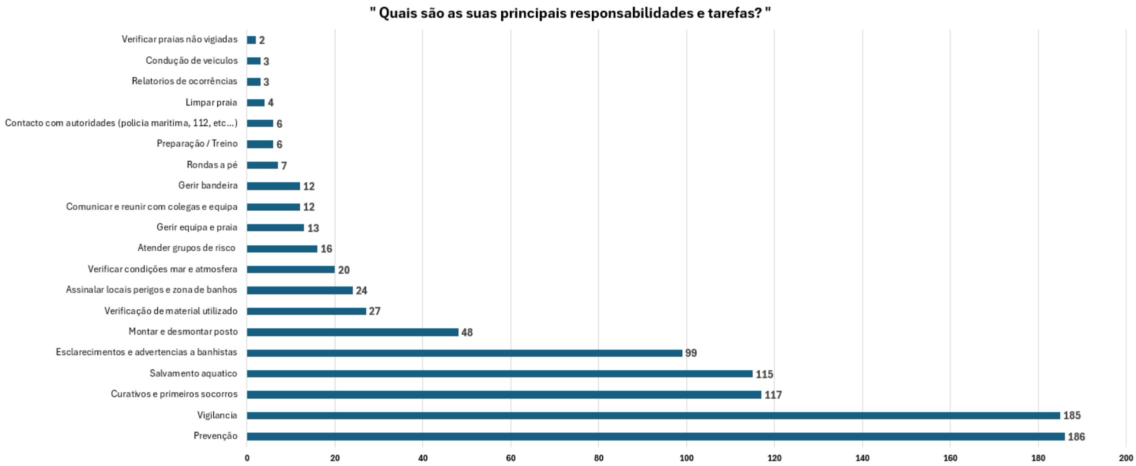


Figure 4.2: All mentions of responsibilities and tasks in Question 3.

4. What kind of equipment and resources do you have available to carry out your job?

Based on the answers given, lifeguards in Portugal rely on a consistent set of equipment:
Rescue gear: *e.g. rescue buoys, rescue boards, fins, poles and rescue tubes.*
Communication tools: *e.g. radios, megaphones and cellphones.*
First aid kits: *Note: defibrillators, oxygen and more advanced material were very rarely mentioned.*
Post infrastructure: *lifeguard towers or chairs, sunshades, flags and signalling tools.*
Visual tools: *binoculars were mentioned frequently, especially for larger beaches or rocky coastlines..*

5. Is there any equipment (or technology) you feel is missing or would like to have to better help you work?

The majority of lifeguards surveyed seem satisfied with their current equipment, even if they can identify missing or faulty material. Communication and surveillance tools are at the top of the list, followed by post infrastructure and digital apps for team coordination.
These answers reveal a blind spot in these systems, where communication and surveillance tools are either lacking or split into various miscellaneous solutions. This reveals a lack of a single, all encompassing system that every lifeguard could use anywhere in the country..

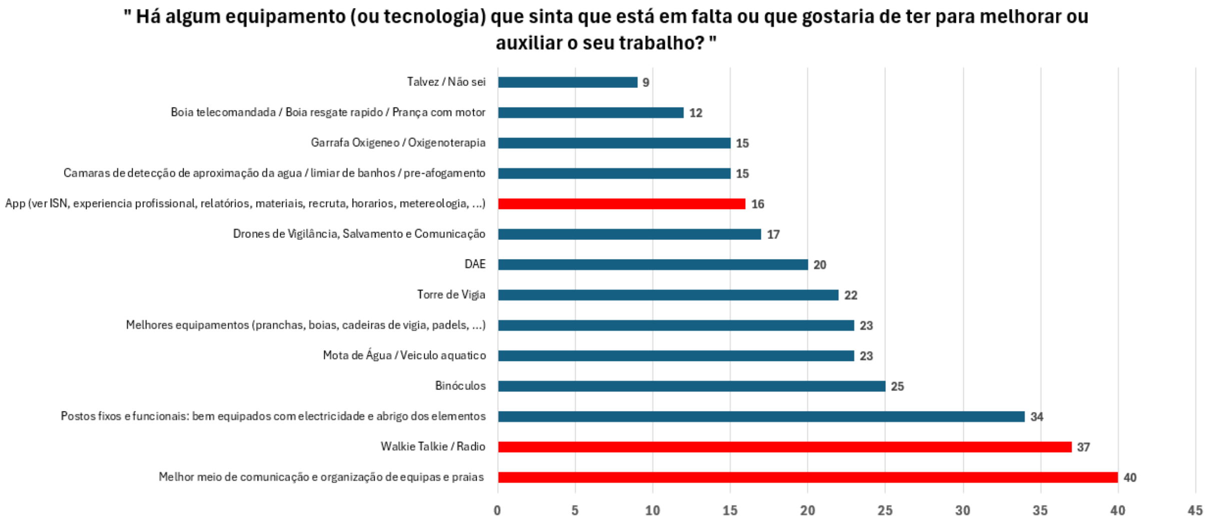


Figure 4.3: Key answers found in Question 5.

6. Are there recurring frustrations at work? How do you handle them?

Lifeguards report a broad range of challenges, the most common being overcrowded beaches and non-compliant or disrespectful beachgoers, both of which directly impact their ability to ensure safety. The natural environment itself — including the rough weather and tides — only add unpredictability to their day to day work.

Emotional and mental stress are also stated to be a major concern. Lifeguards carry a lot of responsibility, and problems with rule enforcement, inadequate pay, lack of support from authorities, team dysfunction and limited resources further compound the difficulty of the job. Many lifeguards work under high amounts of stress and these external factors, although out of their control, impact their effectiveness..

7. How do you deal with frustration or difficulties on the job?

Respondents overwhelmingly rely on emotional self-regulation to handle job-related frustrations, often citing the need to remain calm, neutral, and professional. Many also highlight the importance of talking with colleagues or a team coordinator to decompress and gain perspective. A large portion of answers also reflects a quiet resilience — either by adapting over time or consciously ignoring minor irritations. A minority of lifeguards turn to personal mental health tools (e.g., meditation or exercise), while others admit to struggling with no real strategy in place.

This question reveals a community that is often self-reliant and emotionally disciplined, yet still vulnerable to accumulated stress, especially when isolated or unsupported..

8. How does communication work between lifeguard team members?

Lifeguard team communication is multimodal and situational. The most widely used method is two-way radios, particularly in more structured or larger beach environments. Verbal and visual communication are common when guards are nearby or during low-intensity periods. Interestingly, a significant number of teams rely on personal mobile phones and WhatsApp for

informal communication — a practical solution, though potentially risky in emergencies or official contexts.
Several respondents also express frustration with unreliable or absent tools, especially on more spread-out beaches. In contrast, some emphasize clarity and teamwork, noting that communication works well when protocols and mutual understanding are in place..

9. Do you use any system or technology to keep in touch?

Most lifeguard teams report using radios and mobile phones as their primary communication tools. However, a striking number (87) claim that no formal technology or systems are in use, suggesting that it varies across different beaches and lifeguard teams.
It is also worthy of note that some teams are using consumer communication apps (e.g., WhatsApp), which seems to be the most convenient of options and may be a standard in the future..

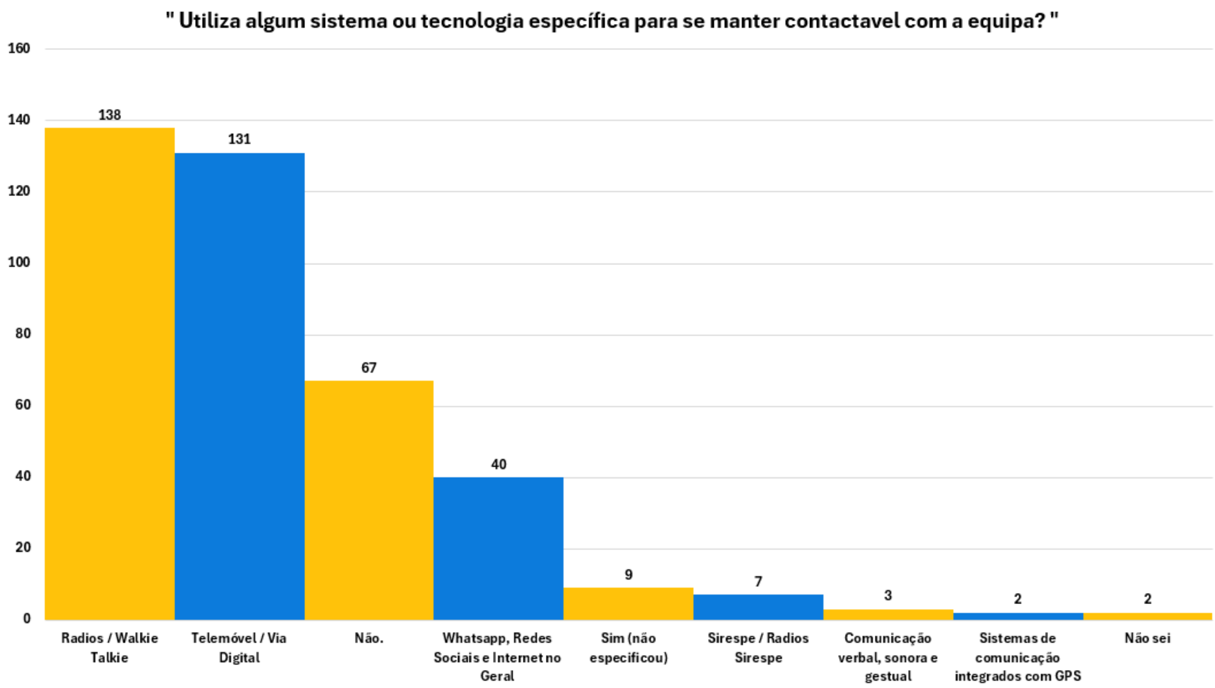


Figure 4.4: Graph of answers to Question 9.

10. How is the organization of lifeguards structured?

Shift structure in lifeguard teams tends to be long and intense, commonly 10-hour shifts, 6 or 7 days per week. This is often coordinated by a team leader or coordinator, with rotating lunch breaks being the standard method for maintaining coverage during meals.
Vigilance areas are generally clearly defined, with posts covering 50 to 100 meters each. There is also a clear awareness of fatigue, leading many teams to implement rotation between static posts and more active beach watch roles.
Still, the data exposes variation in structure (some teams improvise, while others depend on

rigid schedules). A notable portion report concerns with overwork, payment irregularities, or insufficient staff, reflecting broader systemic issues in beach management..

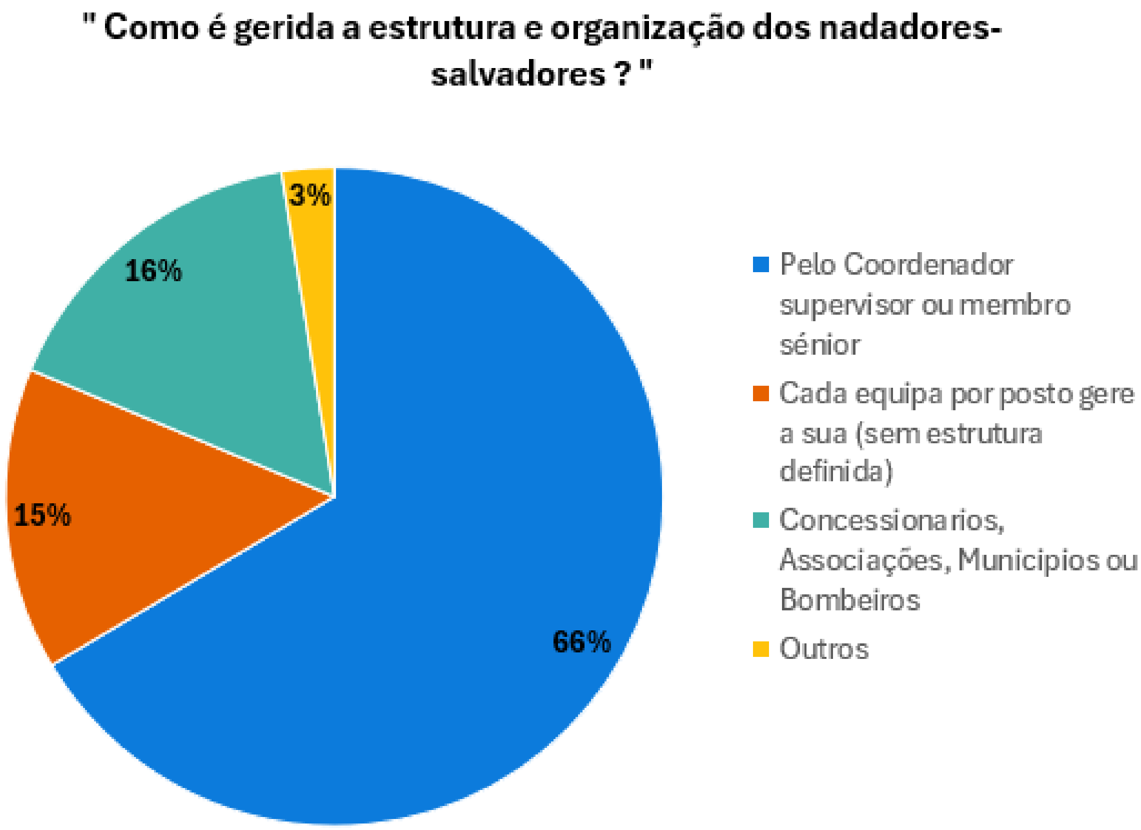


Figure 4.5: Lifeguard station management pie chart

11. If so, how is it managed?

Operational coordination for lifeguards is largely centralized, typically under the guidance of a coordinator or head lifeguard. These individuals define shift schedules, assign vigilance areas, and often mobilize teams during incidents. Associations or concessionaires also play a planning role in some regions.

In a notable subset, team autonomy is the norm — shifts and tasks are agreed upon by the team directly, depending on availability or number of beachgoers. There's frequent rotation between posts, and many beaches use structured planning for lunch breaks to maintain full coverage.

Some teams employ organized systems like alphanumeric codes for post labeling, and integrated planning systems were mentioned in rarer cases..

12. What are the most common situations that require your attention?

The Portuguese lifeguards overwhelmingly identify children as the most at-risk population on monitored beaches. This includes children unattended or playing too close to water. Elderly individuals and pregnant women also figure prominently in perceived risk groups, largely due

to physical frailty or vulnerability in emergencies.
Other mentions include people with disabilities, those swimming far from shore or near riptides, and tourists or foreign individuals whose unfamiliarity with local safety cues may increase risk.
A small number of lifeguards emphasize that everyone is treated equally, though the general trend reveals distinct prioritization based on observable vulnerability..

13. What are some emergencies you have faced?
This question reveals that lifeguards face a wide range of high-risk and life-threatening situations, with drownings or near-drownings being by far the most frequent critical scenario described. These range from children swept away by currents to unconscious adults pulled from the sea. Other significant categories include missing people, often children or the elderly, and serious medical emergencies, such as heart attacks or seizures, which require immediate attention and often emergency service coordination. Injuries from falls, fractures, marine wildlife stings, and bleeding wounds also frequently appear.
Several responses refer to complex, multi-victim rescues, CPR procedures, and occasionally fatal outcomes, underlining the gravity of real-world lifeguard duties..

14. Can you describe the procedure for the case of a drowning?
Lifeguards responding to this question consistently describe a structured and standardized response to drownings or near-drownings. The most cited procedures include activating emergency services (112), performing visual and auditory checks, initiating CPR or basic life support, and relocating the victim to a safe position.
Responses also show strong awareness of correct protocols and rescue algorithms, including proper use of rescue tools and evaluating the victim's level of consciousness. There is also attention to post-rescue care, including the use of oxygen and monitoring for potential complications.
A few respondents expressed that while they haven't performed a real-life drowning rescue, they are trained and describe the theoretical steps clearly..

15. How do you handle stress during emergencies?
Most lifeguards in this survey report that remaining calm is the number one priority when facing stressful rescue situations. For many, training and repetition lead to automatic responses that override panic, allowing actions to be guided by protocol and experience rather than emotion. Numerous responses describe the need to focus entirely on the task or the victim, consciously block out bystanders, and avoid external pressure. Some use breathing techniques or other personal coping strategies to maintain a stable mindset.
Teamwork is also emphasized as a strong buffer against stress, with many indicating that relying on a partner, sharing responsibility, or even voicing procedures aloud helps center focus. A few admit that stress and reflection hit only after the event, showing a clear "performance-first, process-later" mental framework..

Survey Conclusion

The collective responses across all the survey's questions have provided a rich and authentic view into the reality, challenges, strategies and overall behaviour of lifeguards operating in all sorts of contexts and real life scenarios. These first hand accounts are the foundation for SPLASH's user-centered design.
Through this feedback, we were able to extract core themes around the operational structure, stress management, hazard identification, communication and team dynamics currently in use on the field. This allowed the creation of highly representative personas.
These insights reveal nuanced needs, mental models and emotional coping strategies that otherwise could not be captured or understood. The diversity and consistency of the responses not only gave us a data rich foundation for the project's development, but also personally grounded narratives that influenced the future of SPLASH's platform design, from hazard reporting to shift coordination features.

4.2 Stakeholders

The following list presents the key stakeholders (and individuals or groups who have high interest in the project's outcome) identified for the SPLASH system:

- **Primary Stakeholders - Lifeguards:**
  - Play a critical role in ensuring beach safety.
  - Primary users of the SPLASH system.
  - Benefit from tools for real-time monitoring, efficient incident prevention and management, and proactive hazard identification.
  - System designed to support and enhance their performance.
- **Secondary Stakeholders - Beachgoers:**
  - Interact with the web application.
  - View and report beach hazards, providing valuable information for lifeguards.
  - Access information on lifeguard locations.
  - View beach-related information such as weather conditions.
- **Secondary Stakeholders - Beach Business Owners:**
  - Interact with the web application as beachgoers.
  - Can increase their business clientele and profits by accessing premium features through a paid account, which enables them to list their business information, prices, location, and more.
  - Provide an initial monetization avenue for the system.

4.3 Personas, Motivations & User Scenarios

The main personas are described in the following list:

- **Lifeguard Supervisor**
- **Regular Lifeguard**
- **Beachgoer**
- **Business owner**

4.3.1 Lifeguard Supervisor

Biography

Miguel is a 34 year old lifeguard, born on October 14, 1990, in Funchal (Madeira), and raised in Cascais, where he was always immersed in beach life and water activities. Miguel has always held a deep affection for the beaches and sea of his home-town and later embarked on various journeys along Portugal's coastline to experience the country's diverse beaches and tides. Thanks to his lifelong connection to the sea, Miguel knew he wanted to work close to it. He took a degree in Physical Education and Sports while also completing certifications as a lifeguard and teacher. He began working as a lifeguard during beach seasons, and outside of these periods, he worked in gyms and fitness academies, teaching swimming and functional training.

Miguel's first experience as a lifeguard was both enriching and challenging. His training provided him with all the tools he needed for the job, but theoretical knowledge couldn't replace the practical skills acquired on the field. He initially struggled with maintaining near-constant focus on beach-goers and often found himself frustrated by swimmers choosing less visible spots. Thankfully, his more experienced colleague supported him every step of the way. Today, Miguel considers the most important lesson from those early days to be the value of having a mentor during the learning process. In the years that followed, Miguel worked as a Swimming Instructor and Swimming Team Coach, roles that complemented and were complemented by his work as a lifeguard. At 28, he became a Physical Education Teacher. Here, he directly experienced some of the frustrations of parents he had often observed at the beach, trying their best to supervise children or manage certain activities.

Now considered a veteran within the lifeguard community, Miguel takes on the role of mentor for novices and aspiring lifeguards who choose to embrace the challenge. He recognizes in their mistakes and frustrations the same ones he experienced many years ago. But while some things remain unchanged, many others have evolved. Technology has advanced exponentially since his childhood. Mobile phones have become smartphones, the internet is now wirelessly accessible, and weather forecasts have become more accurate and available in real-time. Miguel also sees a stronger attachment to technology among the newer generations and a greater disconnect from the environment. He believes that with the right approach, technology can be used to complement human limitations.

Motivation

Miguel wants to improve the management of lifeguard teams. He seeks a broader and more integrated view of the beach environment, as well as tools for signalling hazardous situations.

Mega Scenario: "A Summer Day: Management and Surveillance"

Scenario 1: *Miguel Logs in to Monitor the Beach and Approves a New Lifeguard Registration*

Miguel starts his day by checking the beach monitoring system. He accesses the required URL, clicks on Login, and enters his credentials before clicking "Submit." He then views the camera activity and hazard zones on the interactive map. While observing the beach in real-time, he ensures that the busiest areas are monitored and adjusts the interactive map to assign teams to specific monitoring zones by clicking on the location of each lifeguard post and allocating team members based on their schedules via the “Schedule” tab.

A few minutes later, he receives information about the registration of a new lifeguard. Miguel accesses the “Team Management” section and confirms the registration by clicking the “Accept” button, allowing the new team member to begin their duties.

Scenario 2: *Miguel Receives a Request to Analyze a Hazard Zone for Weever Fish Stings and Sends a Lifeguard to Investigate*

Miguel receives an alert on his interactive map. He clicks on the red circle with the “eye” icon and sees that a beachgoer has requested an analysis of a hazard zone due to “Weever Fish Sting.” Miguel quickly clicks the “Send Lifeguard” button and selects the nearest lifeguard to investigate. Moments later, the hazard zone is confirmed by his colleague. Miguel then adjusts the hazard zone settings, draws the specific area on the screen with his finger, and clicks “Issue Alert,” sending a visual notification (map drawing) to all beachgoers with system access, indicating the danger zone. He feels satisfied knowing the information is quickly disseminated, ensuring safety.

Scenario 3: *Miguel Receives an Emergency Notification About a Lost Child*

An alert notification arrives on his system: “Bracelet associated with a child is emitting an alert signal.” Miguel immediately clicks the “Respond” button and, with the guardian’s automatic authorization, checks the GPS location of the child. He then clicks the “Send Lifeguard” button, assigning lifeguard Joana Costa, who is the closest to the child’s location, to the emergency. Joana quickly proceeds to handle the situation.

Scenario 4: *Miguel Observes and Coordinates the Rescue of a Swimmer Using a Drone and Detection Cameras*

Through the camera mounted at the lifeguard post, Miguel notices that a swimmer, Maria Fernandes, has crossed the safety limit and appears to be in trouble in the water. Based on his experience, he quickly deduces that Maria is suffering from a cramp and is in a location where she cannot touch the bottom. Miguel immediately clicks the “Pre-Drowning” button and marks the approximate location on the map, alerting the nearest lifeguard.

He then clicks the “Send Drone” button, puts on the VR goggles, and takes control of Rescue Drone No. 1, which emits its GPS location to the field lifeguard system. Moments later, the drone reaches Maria’s location, and Miguel uses the drone’s speaker to communicate: “Stay calm. I’m dropping a rescue buoy. Hold on and stretch your leg to relieve the cramp. Help is on the way.” He commands the drone to release the rescue buoy. Shortly after, lifeguard Joana Costa arrives to assist Maria.

After resolving the issue, Miguel accesses the interactive map in the application, draws a red circle around the dangerous area, and marks it as “Rip Current,” sending a visual notification (drawing) to beachgoers and colleagues about the zone.

Scenario 5: *Miguel Corrects Errors by Analysing Weather Conditions, Updates the Flag Status, and Accesses the Beach History and Metrics*

Miguel accesses his interactive map and reviews the "Weather Conditions" tab, which shows favourable conditions for beach activities (Temperature: 35ºC, Waves: 0.5 meters, Wind: 1 km/h, etc.). He verifies that the flagged status is correct (green) but notices that the system indicates the wrong flag. He clicks on the yellow flag icon at the respective post and changes it to "Green."

Later, he accesses the "History and Metrics" tab. This section provides a complete history and metrics of the beach (e.g., Problematic Areas, Average Number of Incidents per Month/Year). Using this data, Miguel begins to design future safety strategies based on the insights from this section.

End of the Mega Scenario

At the end of the day, Miguel reflects on how technology has improved communication and the efficiency of his team.

4.3.2 Regular Lifeguard

Biography

Joana Costa is a 19 year old lifeguard, born on April 26,2005 , in Portimão. From an early age, her connection to the sea shaped her passion for the beach and aquatic environments. At just two years old, she began swimming and, over the years, developed into a talented competitive athlete.

In 2023, Joana decided to follow her passion and enrolled in the Bachelor's program in Sports Science at the University of Coimbra. However, after a few months in the course, her parents realized they couldn't financially support her studies beyond the first year due to the rising cost of living. Determined not to give up on her goals, Joana sought a solution and enrolled in the Lifeguard Training Course at EFNSP.

With her experience as an athlete and her deep knowledge of the aquatic environment, Joana easily passed both the physical and theoretical tests, completing the course in January 2024. By late May, she was preparing to begin her first summer season as a lifeguard. Accustomed to the calm, warm waters of the Algarve, Joana was eager to face new challenges on the beaches of the central region.

However, her first day on the job brought an unexpected twist. What started as a calm, sunny afternoon quickly changed with the arrival of a dense fog from the north, drastically reducing visibility. Concerned about the large number of swimmers in the water, Joana remained vigilant.

Suddenly, a man approached her, visibly distressed, reporting that his 13-year-old son, who had been bodyboarding, was missing. In a mix of adrenaline and focus, Joana used her binoculars to try to locate the boy, but the dense fog made it impossible to spot him. Without hesitation, she grabbed her board and entered the water to search for the boy. After 15 minutes of searching with no success, she reported the disappearance to the maritime police.

Fortunately, the rescue was successful, and the boy was found being carried by a current, with no serious injuries. Despite the positive outcome, the incident left Joana emotionally shaken. The feeling of helplessness for not being able to act faster stayed with her, challenging her to become even more vigilant and prepared for future emergencies.

Motivation

Joana would like to have a broader view of the beach she monitors and better communication with her colleagues.

Mega Scenario: "A Day of Action for Joana"

Scenario 1: *Joana Arrives at an Unknown Beach and Logs in as a Lifeguard to Start her Shift*

Joana arrives at a new beach, excited for her first day as a lifeguard. At the entrance, she notices a QR code and decides to scan it. Joana creates an account (Sign in) and logs in. The tablet provides information about the beach, including the presence of dangerous currents and the location of other lifeguards. Two minutes later, she receives confirmation that her account has been approved by the supervising lifeguard, "Miguel Soares," along with details about her schedule, team, and assigned station. This information boosts her confidence, knowing she can rely on her team's support.

Scenario 2: *Joana Receives an Emergency Alert "Lost Child"*

While monitoring the beach from her chair, Joana receives a notification on her device: "ALERT: Swimmer in difficulty." She quickly heads to the area indicated on the interactive map and encounters a worried father, Ricardo, who is trying to locate his son who has drifted too far. Joana uses a GPS bracelet to help Ricardo determine the child's location. Following the tablet's instructions, Joana quickly finds the child playing with other kids. Relieved, she brings the child back to the safe area where Ricardo is anxiously waiting. Grateful for her swift action and the use of technology that facilitated locating his son, Ricardo thanks Joana deeply. Joana then logs into her tablet and marks the situation as "Successfully Resolved."

Scenario 3: *Joana Is Notified to Analyse a Potential Danger Zone on the Sand*

During her shift, Joana receives an alert on her device: "ALERT: Danger, Debris on the Sand," reported by a beachgoer. She quickly moves to the indicated location, where she finds broken glass, confirming the alert's accuracy. Joana physically cordons off the dangerous area and uses her tablet to alert her supervisor, Miguel, enabling him to contact the appropriate services to clean the site.

Scenario 4: *Joana Is Alerted to an Emergency and Rescues a Swimmer in Pre-Drowning*

During her shift, Joana notices a drone flying over the beach. Miguel, who is at the command post, informs her via tablet about a situation where a swimmer is drifting into open water. Using the tablet, Joana quickly confirms the swimmer's location and heads into the water. Upon entering, she spots the swimmer, Maria, in distress. Following Miguel's instructions, she uses a rescue buoy dropped by the drone to successfully save Maria.

Scenario 5: *Joana Requests a Schedule Change and Performs Shift Handover*

As her shift comes to an end, Joana is notified via tablet that she is about to be relieved by her colleague, “Eduardo Monteiro,” who will meet her at her station. Joana reviews her schedule and notices a conflict for the following Thursday due to a medical appointment. She clicks on the “Lifeguard Hub” button, selects “My Schedule,” and accesses the “Calendar” option. She then clicks on “Request Change,” providing the reason for the request. Next, she selects “Shift Handover,” where she inputs relevant details about her shift for her replacement.

End of the Mega Scenario

After an intense workday, Joana reflects on the importance of technology for performing rescues and fostering collaboration among lifeguards. She realizes that, even as a newcomer to the profession, she can make a significant difference with the right support.

4.3.3 Business owner

Biography

Ricardo, a 40 year old beach bar owner and occasional vendor of American waffles, lives in Vila Nova de Gaia and inherited the business from his father, which is why he didn’t pursue higher education. He is married to the woman he met in his youth, and together they have two children, aged 10 and 7. One of his favourite hobbies is going to the beach with his family to enjoy quality time together.

One summer day, Ricardo went to the beach with his family, but upon arrival, he discovered that the beach was not supervised. He became worried about his children’s safety since he didn’t know how to identify the most dangerous areas and had no way of predicting this situation before leaving home.

On another occasion, Ricardo took his children alone to a supervised beach, but it was very crowded, making it difficult for him to watch over both kids at the same time. This caused him more concern and limited his enjoyment of the outing.

Motivation

Ricardo would like to have a way to receive information about the beach he is visiting and an easier way to monitor his children while they are at the beach.

Mega Scenario: “A Summer Day in Ricardo’s Life”

On a sunny morning, Ricardo, a 40-year-old father, decides to enjoy his day off with his wife and two children, aged 10 and 7. Excited, the family prepares their beach essentials, applying sunscreen and packing snacks and sand toys into a bag. After a short 20-minute car ride, they arrive at their favourite beach, eager for a relaxing day.

Scenario 1: *Ricardo Visits an Unsupervised Beach and Uses the App to Get Beach Information*

Upon arriving at the beach, Ricardo notices something unsettling: the beach is not supervised by lifeguards that day. As a protective father, he quickly feels the responsibility to ensure his children's safety. With his heart racing and worried about currents and potential hazards, he begins to look for solutions.

Noticing a QR code posted at the beach entrance, Ricardo scans it with his phone. The code redirects him to a website with detailed information about the beach conditions. The technology provides him with a sense of relief. On the site, he finds a map indicating areas with weaker currents and the location of submerged rocks — crucial information for ensuring his family's safety. The site also offers safety tips for dealing with unsupervised beaches, which reassures Ricardo.

Armed with this knowledge, Ricardo takes a deep breath and guides his family to a designated safe area. There, they can finally relax and enjoy their day without the constant feeling of imminent danger. Still attentive, Ricardo feels more at ease knowing he is well-informed.

Scenario 2: *Ricardo Visits a Supervised Beach Offering GPS Bracelets*

Later, after lunch, Ricardo's wife returns to work, and he decides to head back to the beach with his two children. This time, the beach is supervised, and upon advice from another beachgoer, Maria Fernandes, he scans the QR code again and discovers something new. The site informs him that the lifeguard post offers a GPS bracelet system to monitor children. This immediately captures his attention, as being alone with two active children makes him feel the need for additional safety measures.

Ricardo approaches the lifeguard post, where he meets Joana, a young lifeguard who assists him. She explains that the GPS bracelets allow real-time monitoring of children's locations and send alerts if they stray beyond a predefined radius. Impressed, Ricardo decides to rent three bracelets: one for himself and two for his children.

Throughout the afternoon, Ricardo relaxes while watching his children play, with the added peace of mind that he will be immediately notified if something happens. Whenever one of the children tries to leave the safe area, Ricardo's bracelet vibrates softly, alerting him to call his children back.

Scenario 3: *One of Ricardo's Children Disappears on the Beach with the GPS Bracelet*

Near the end of the afternoon, as Ricardo relaxes, he feels a vibration on his wrist. One of his children has wandered beyond the safe zone set by the GPS bracelet. Ricardo's heart races. He looks around, but the crowded beach makes it difficult to locate his child immediately. Panic begins to set in.

Realizing his child is missing, Ricardo rushes to Joana, the lifeguard. He quickly explains the situation, and Joana, calm and experienced, asks if the child is wearing one of the GPS bracelets. Ricardo confirms, and Joana uses a tablet equipped with a compatible reader. By linking Ricardo's bracelet to the system, Joana quickly locates the exact position of all family members and identifies Ricardo's child.

The tablet shows the child is further away, playing with other kids. The tension in Ricardo's chest eases as Joana accompanies him to where his child is, safe and sound. Relieved, Ricardo thanks her for her help and reflects on how this technology made a huge difference during such a stressful moment.

Scenario 4: *Ricardo Upgrades His Account to Premium*

Back at his beach bar, Ricardo accesses the application and notices a new button labeled "Promote Beach Business." Curious, he clicks on it and learns that, for a modest monthly fee, he can upgrade his user account to a premium account. This allows him to promote his business by displaying information such as "Profile Picture," "Business Name," "Business Type," "GPS Location," "Description," "Products," and "Prices."

Ricardo clicks the "Get Premium Account" button and is redirected to the plan selection and payment page. After selecting a plan and payment method, he enters the necessary credentials and completes the payment, obtaining a premium account. He then clicks on the new "Manage Business" button and accesses the business management menu. Ricardo updates his profile by editing the relevant fields such as "Profile Picture," "Business Name," "Business Type," and "Description." After submitting the changes, he returns to the business management menu and begins adding his products, prices, and promotions.

End of the Day

As the sun sets, Ricardo and his children return home, tired but happy. Reflecting on the day, he realizes how small technologies, such as the simple QR code at the beach entrance and the GPS bracelets, made a big difference. These innovations not only ensured his children's safety but also gave him peace of mind that would have been hard to achieve without them. More than just a fun day, it was a day of trust and security.

4.3.4 Beachgoer

Biography

Maria is an experienced nurse, 49 years old, born on February 7, 1975, in Braga. She grew up in Vila do Conde with her sister Regina, where they spent summers at the local beach, making Maria a regular beachgoer and nurturing her special affection for the sea.

One day, Maria was swimming at Armação de Pêra beach, which she had never visited before. Suddenly, she realized she was drifting far from the shore, and no matter how hard she tried to swim back, she was being pulled further out to sea. To make matters worse, she began to experience a cramp in her left leg, severely hindering her ability to move. Fortunately, Maria managed to catch the attention of a lifeguard who reached her several meters from the shore. He handed her a rescue buoy, stretched her leg to treat the cramp, and advised her to swim perpendicular to the shoreline to escape the rip current. Exhausted and shaken, Maria made it back to the sand. She hadn't known about the rip current in that area, which left her feeling apprehensive. She decided not to swim anymore that day and opted instead to take a walk along the water's edge.

During her walk, Maria ventured beyond the lighthouse, but upon her return, she realized the area was flooded due to the high tide. She had to use a staircase several meters away to access the promenade and return to safety. This experience frustrated her, as she had to walk much further to find an accessible staircase, leaving her very tired.

Maria earned her nursing degree from the Escola Superior de Enfermagem de Coimbra. With 25 years of professional experience, she specialized in critical care nursing and has worked in an Intensive Care Unit, treating numerous cases of patients in post-drowning situations.

Her personal and professional experiences have shaped her attitude toward beach safety. Maria prefers to visit beaches supervised by lifeguards, understanding the potential dangers of the sea. However, she is aware that it's not always easy to determine whether a beach is supervised or to identify hazardous areas within the same beach.

At 49 years old, Maria reflects on how the beach can be a relaxing activity but also potentially dangerous without adequate rescue resources or supervision.

Motivation

Maria would like to have a technological solution that provides information about hazardous areas and the safety of the beaches she may visit.

Mega Scenario: "A Day at Praia da Rocha"

It was a sunny day at Praia da Rocha, one of the most popular beaches in the Algarve. Maria de Lurdes da Silva Fernandes, a 49-year-old nurse, was about to experience a day at the beach that would change her perspective on beach safety, thanks to innovative technologies.

Scenario 1: *Maria Uses the App to Learn More About the Beach*

Upon arriving at Praia da Rocha, Maria notices a QR code on a sign at the entrance that reads: "Access our app for more information about this beach." Curious, she scans the code with her smartphone and is redirected to an app displaying an interactive map of the beach. The map provides relevant information such as submerged rocks, areas with strong currents and rip currents, the locations of lifeguards, and more, all clearly marked.

In the top corner, she sees an icon indicating the current flag status ("green"), confirming that the beach is supervised, along with the UV radiation level.

Scenario 2: *Maria Pairs Her Smartband with the App*

After setting up her beach umbrella and towel, Maria opens the app to pair her waterproof Smartband. She clicks on the menu icon in the top-left corner (three horizontal lines) and selects the "Pairing" option from the dropdown menu. Then, she clicks "Scan QR Code" and scans the QR code on her Smartband. Now, she can receive alerts while swimming.

Scenario 3: *Maria Receives Alerts on Her Smartband*

Eager to enjoy the water, Maria enters the sea. After a few minutes of swimming, her Smartband vibrates, displaying a notification: "Caution: Strong currents 5 meters ahead." The alert is accompanied by a visual warning on the band's display. Feeling prepared, Maria changes direction and swims away from the dangerous area.

Scenario 4: *Maria Experiences Difficulties and Receives Help from a Drone*

Unfortunately, while enjoying the water, Maria experiences a cramp in her leg. She struggles against the waves, trying to return to shore, but the pain is severe. Suddenly, a drone flies overhead. Through its speaker, she hears the calm voice of veteran lifeguard Miguel Soares from the command post: "Stay calm. I'm dropping a buoy. Hold on and stretch your leg to relieve the cramp. Help is on the way." Following his instructions, Maria takes deep breaths and swims in the suggested direction. Within minutes, she sees Joana Costa, the novice lifeguard, approaching to assist her.

Scenario 5: *Maria Searches for Beach Bars Using the App*

Feeling hungry, Maria opens the app to search for places to eat on the beach. On the main screen (the beach map), she notices two bars marked on the interactive map. Clicking on one of the locations redirects her to a page displaying the bar's name, menu, and prices.

Scenario 6: *Maria Receives a Notification About a High Tide Area*

After eating, Maria decides to take a walk along the shore. While enjoying the view, her smartphone vibrates with a notification: "Caution! The area ahead is prone to flooding during high tide. In 50 meters, you will enter an unsupervised area." Grateful for the warning, she decides to return to a safer area, avoiding any risk.

Scenario 7: *Maria Reports Hazardous Glass on the Sand*

While walking along the beach, Maria notices broken glass on the sand. She takes out her smartphone, opens the app, and clicks on her current location on the interactive map to access reporting options. Selecting "Report Issue," she chooses "Hazardous Waste" and then "Glass," finally clicking "Submit." A confirmation pop-up appears: "Issue Reported." Satisfied, Maria continues her walk, taking extra care to avoid stepping on any glass.

Scenario 8: *Maria Assists an Injured Beachgoer and Requests Help*

Maria sees an elderly man in difficulty on the beach. As a nurse, she examines the wound on his foot and recommends that he seek help from the nearest lifeguard for first aid. However, the man struggles to walk due to the injury. Maria opens the app and presses the "Help Button." Within minutes, a lifeguard from the area arrives to assist the man.

Scenario 9: *Maria Locates a Berlin Ball Vendor*

Maria feels like having a snack, so she opens the app to see her options. On the interactive map, she notices a moving icon representing a Berlin Ball vendor, as well as another icon for ice cream. She decides on the Berlin Ball and heads toward the vendor to make a purchase.

End of the Day

Maria returns home and reflects on how technological innovations transformed her beach experience. With Smartbands, drones, and the interactive app, she felt safer and more confident. The sea, which once seemed risky, now feels like a space she can enjoy with others, knowing that safety is just a touch away.

4.4 Functional and Non-Functional Requirements

This section outlines the system requirements specification developed during the initial phase of prototype development. It includes an overview of the personas and scenarios created, followed by the requirements elicitation, which was based on the analysis of their needs. Additionally, it covers the non-functional requirements, as well as the system assumptions and dependencies.

4.4.1 Functional Requirements

Functional requirements define the specific functionalities that the SPLASH system must have to meet the project's needs. Based on the personas, scenarios, and use cases identified, the following functional requirements have been defined:

1. **Interactive Maps and Real-Time Information:** The system must provide users (lifeguards and beachgoers) with an interactive map in real time, displaying safety information on the beach, the location of dangerous areas, and available resources.
2. **Report and Alert of Hazard Zones:** The system must enable the report hazard zones, such as areas with a risk of weever fish stings, and generate visual alerts visible to all platform users, including lifeguards and beachgoers.
3. **Data History:** The system must be able to store data related to incidents and beach metrics like weather.
4. **Resource Management:** The system must allow the coordinator (Miguel, in the use case scenario) to dispatch lifeguards to specific locations based on beachgoer requests or real-time hazard detection, ensuring a quick and efficient response.
5. **Real-Time Communication:** The system must enable direct communication between the lifeguard team and coordinators, with the ability to transmit alerts, situation updates, and instructions effectively.
6. **Resource Management and Lifeguard Coordination:** The system must enable efficient management of all resources involved in lifeguard operations, including lifeguards, equipment, and infrastructure, with functionality to monitor and adjust operations in real time.
7. **Alerts for Beachgoers:** The system must generate visual and audible alerts for beachgoers whenever a hazard zone is identified to ensure their safety and prevent accidents.
8. **Access to Beach Information:** The system must provide information on weather conditions, beach amenities, and available services, such as restaurants and surf schools, to enhance the beachgoers experience.

4.4.2 Non-Functional Requirements

Non-functional requirements define the quality attributes that the SPLASH system must meet to ensure its proper operation. These requirements are not directly related to specific functionalities, but they are essential for ensuring the system's effectiveness and reliability.

1. **Performance and Scalability:** The system must provide responses with low latency, ensuring real-time interactions with a maximum response time of approximately 3 seconds.
2. **Availability and Usability:** The system must be user-friendly and intuitive, achieving a System Usability Scale (SUS) score of 70% or higher to ensure ease of use for lifeguards, coordinators, and beachgoers.
3. **Data Security:** The system must guarantee the protection of personal user data, such as contact information and location, complying with security and privacy regulations.
4. **Performance and Scalability:** The system must operate efficiently, even during traffic peaks, such as at high attendance times on the beaches, without affecting the user experience.
5. **Resilience to Adverse Conditions:** The system must be resilient to failures caused by adverse conditions, such as extreme weather (e.g., storms or intense sunlight) that could affect sensors or the communication network.
6. **Maintainability and Upgrades:** The system must allow for easy maintenance and upgrades, enabling the implementation of new features or improvements without disrupting current operations.

4.5 Task Analysis

By examining the scenarios derived from the project's personas, the Hierarchical Task Analysis (HTA) decomposes each high-level user goal into a structured tree of sub-goals, tasks and operations. This explicit decomposition reveals where users encounter choice points, where loops of repeated activity occur, and which operations carry the greatest cognitive load or risk of error. Those insights directly inform interface design by identifying opportunities to automate repetitive work, group related controls, provide real-time feedback, and prevent or recover from common mistakes. The complete four-level HTA diagram appears in Appendix .1 (Figure .1), showing every branch of the analysis from top-level goals down to atomic operations.

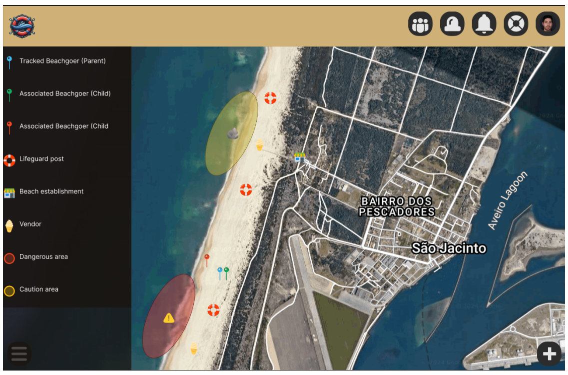
CHAPTER 5

Low-Fidelity Prototypes

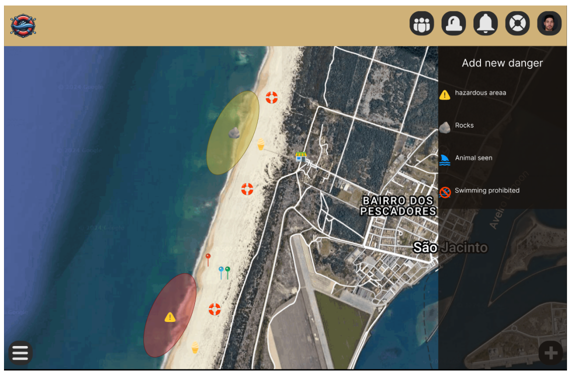
Low-fidelity prototypes are basic, early-stage representations of a product's interface. They are used to rapidly explore design ideas, test usability, and gather feedback before progressing to high-fidelity design and full development.

5.1 Mockups

For the SPLASH project, **Figma** was initially used as a collaborative tool for brainstorming and sketching early interface concepts. Its real-time collaboration features allowed team members to quickly share and iterate on ideas during the early design phase, as illustrated in the figures below:



(a) SPLASH mockup: Index menu open on map



(b) SPLASH mockup: Add hazard menu open on map

Figure 5.1: Early-stage design brainstorming using Figma. For a more detailed and interactive view, access the full project here: SPLASH Figma Design.

Once the general layout and structure of the interface had been agreed upon, the team transitioned to **Microsoft PowerPoint** to develop all mockups in detail. PowerPoint was chosen due to its familiarity among all team members and its ease of use for quickly assembling and customizing interface elements. The mockups were collaboratively developed using the team's shared **OneDrive** workspace, which ensured effective version control and feedback. Below are several images showcasing the final low-fidelity prototypes developed using **Microsoft PowerPoint**:

As illustrated (Figure 5.2), the main feature of SPLASH is an interactive map that allows users to navigate and access detailed beach information. At this stage, the interactive map enables users to view their GPS location, the positions of lifeguard posts, the real-time locations of individual lifeguards, as well as the locations of restrooms, beach bars, restaurants, and mobile vendors.

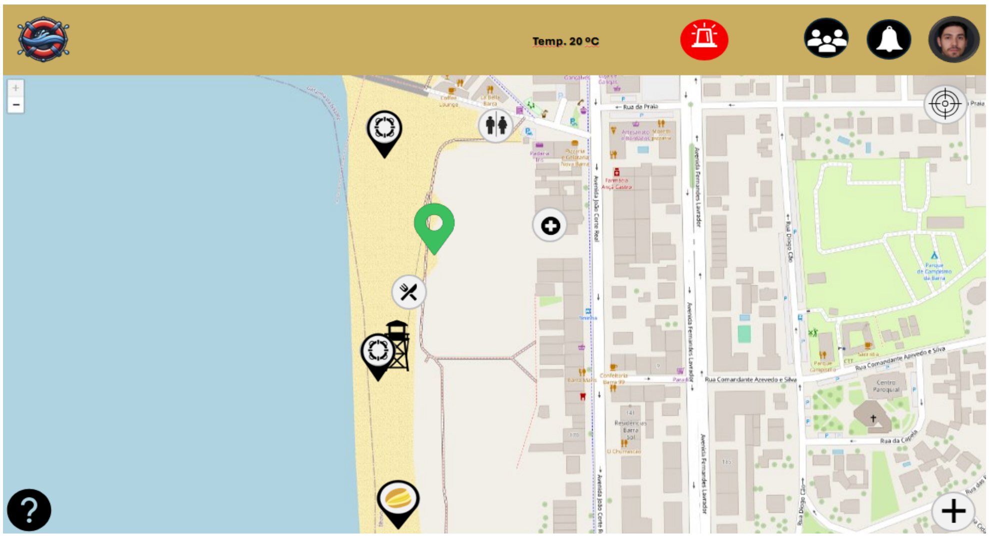
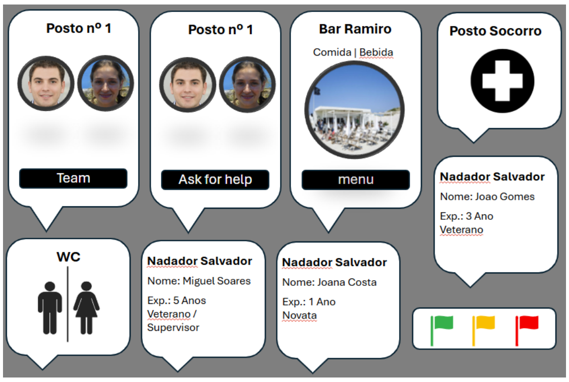


Figure 5.2: SPLASH mockup: Interactive Map

Additionally, the map features a variety of menus and pop-ups (Figure 5.3) that appear when users click on specific icons. These include detailed information and editing options for guard posts, general information about lifeguards, and menus for bars and restaurants. Users can also consult a legend for icon clarification and report new hazards they encounter on the beach.

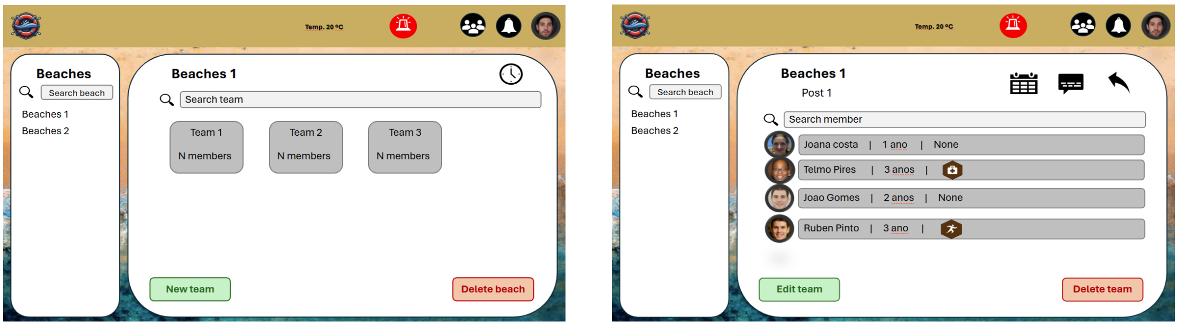
(a) SPLASH mockup: Interactive Map Menus



(b) SPLASH mockup: Interactive Map Pop-ups

Figure 5.3: Examples of interactive menus and pop-ups in the SPLASH map prototype.

The application features dedicated menus for organizing teams and managing lifeguard assignments at each beach (Figure 5.5). The beach teams menu (left) allows users to browse available beaches, search for specific teams, and view the number of members in each team. Users can easily create new teams or delete entire beaches as needed. The beach guard posts menu (right) provides a detailed view of team members assigned to a specific post, including their names, years of experience, and relevant roles or certifications. This interface supports quick editing of team compositions.

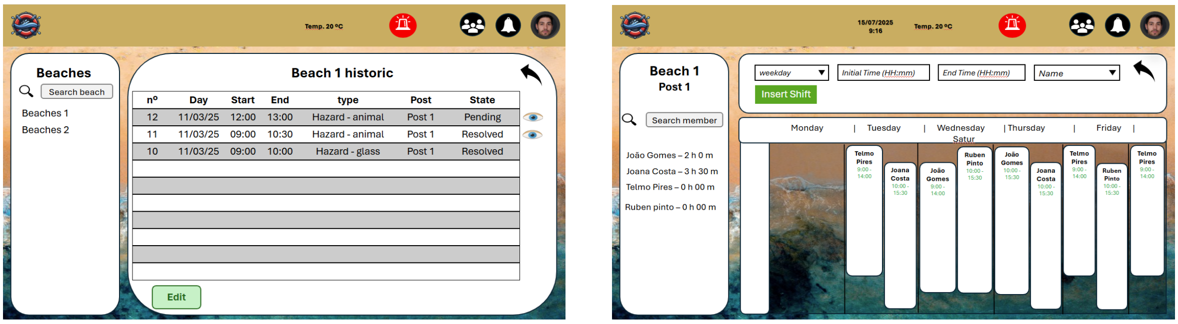


(a) SPLASH mockup: Beach teams menu

(b) SPLASH: Beach guard posts menu

Figure 5.4: some caption...

The application also provides dedicated interfaces for managing beach safety operations (Figure 5.5). On the left, users can access a comprehensive hazard history for each beach, displaying a chronological list of recorded incidents with details such as date, time, hazard type, affected post, and current status. This facilitates efficient monitoring and resolution of safety issues. On the right, the scheduling menu allows managers to organize and visualize weekly staff assignments for each beach guard post. Users can filter by member, day, and shift times, ensuring optimal coverage and clear oversight of lifeguard duties throughout the week.



(a) SPLASH: Beach's hazard history

(b) SPLASH: Beach guard posts schedules

Figure 5.5: some caption...

Furthermore, PowerPoint enabled the team to print and cut out each interface screen, which was essential for conducting hands-on usability testing sessions, discussed in chapter 7. This practical approach allowed users to simulate interactions and provide valuable feedback during early development stages.

A complete version of the mockups is available online at: `https://github.com/SPLASHub/`

`SplashDocumentation`.

These low-fidelity prototypes played a central role in the early design validation process. Not only did they enable quick iterations and collective design decisions, but they also formed the foundation for the usability testing procedures described in the following chapter.
In particular, the printed and cut-out mockups were instrumental in simulating realistic interactions through the Wizard of Oz technique, providing valuable insights into how users engaged with the interface concepts and navigation flow.

To ensure that the SPLASH system aligns with user needs and expectations, a usability evaluation was conducted using the low-fidelity prototypes presented in Chapter 5. This process was designed to identify usability issues at an early stage and to guide subsequent improvements prior to further development.

5.2 Methods

5.2.1 Wizard of Oz Approach

The Wizard of Oz approach was utilized as a prototyping technique in which users interacted with what appeared to be a functioning system, while all functionalities were operated by a human behind the scenes. This method enabled the simulation of key features of SPLASH and facilitated the observation of authentic user interactions.

5.2.2 Usability Testing Procedure

- **Participants:** Five individuals participated in the usability tests, representing typical end-users of the SPLASH system. This sample size is considered sufficient for identifying the majority of usability issues in formative evaluations.
- **Testing Environment:** System responses were simulated by the test facilitator as required, following the Wizard of Oz methodology.
- **Tasks:** Participants were instructed to complete a series of representative tasks, including navigating the interactive map, locating lifeguard posts, and reporting a beach hazard.
- **Observation and Think-Aloud Protocol:** User actions were observed throughout the testing process, and participants were encouraged to verbalize their thoughts, decisions, and any encountered difficulties, following the think-aloud method.
- **Post-Test Feedback:** Upon completion of the tasks, participants provided feedback through a brief interview and completed a usability questionnaire (System Usability Scale (SUS)).

5.3 Evaluation Objective

The primary objective of this usability evaluation is to achieve a System Usability Scale (System Usability Scale (SUS)) score of at least 70%, which is recognized as a benchmark for acceptable usability in interactive systems.

5.4 Expected Results

Based on established usability testing practices, the evaluation is expected to identify:

- Areas of confusion or difficulty within the interface;
- Features that are intuitive and support user goals;
- Suggestions for improvement provided by participants;
- An overall usability score (derived from the SUS questionnaire) to benchmark the prototype's effectiveness.

5.5 Summary

The usability evaluation, utilizing the Wizard of Oz approach and structured user testing, provided valuable insights into the strengths and weaknesses of the SPLASH prototype, informing subsequent design iterations and supporting the development of a user-centered final system.

Figure 5.6: SPLASH: Photograph captured during a usability testing session with users

5.6 Conclusion

These low-fidelity prototypes enabled quick iterations and collective design decisions, forming the foundation for the usability testing procedures described in the following chapter. The printed and cut-out mockups were instrumental in simulating realistic interactions through the Wizard of Oz technique, providing valuable insights into how users engaged with the interface concepts and navigation flow.

CHAPTER 6

System Design and Architecture

Design and architecture constitute critical determinants of the SPLASH system's functionality, efficiency, and scalability. This section details the foundational components of the SPLASH proof-of-concept, demonstrating the integration of elements to create a cohesive solution for a beach preventive safety management.
Key diagrams illustrate the system's architecture and operational framework. Each diagram provides unique insight into specific aspects of the system, clarifying its structure and functional relationships.
Analysis of these diagrams advances understanding of the SPLASH system's design principles and operational capabilities, establishing a basis for further investigation into implementation and potential contributions.

6.1 Context Diagram

The context diagram in Figure 6.1 defines the system's boundaries and interactions with external entities, including users, environmental sensors, emergency services, and third-party data providers. It clarifies input/output flows, such as hazard alerts, sensor data streams, and user requests, while omitting internal implementation details. This diagram establishes the scope of the SPLASH system within the broader beach safety ecosystem.

The context diagram in Figure 6.1 describes the SPLASH system's boundaries and its interactions with key external stakeholders such as Supervisor Lifeguards, Regular Lifeguards, Beachgoers, and Beach Business Owners (concessionaires). The diagram illustrates the bidirectional flow of generic information, such as new updates, authorized beach information, and business metrics, between the system and each external entity. By mapping these exchanges, the diagram clarifies the roles and data dependencies of all parties involved, while abstracting away internal system details. This representation defines the operational scope of the SPLASH system within the management environment of a beach.

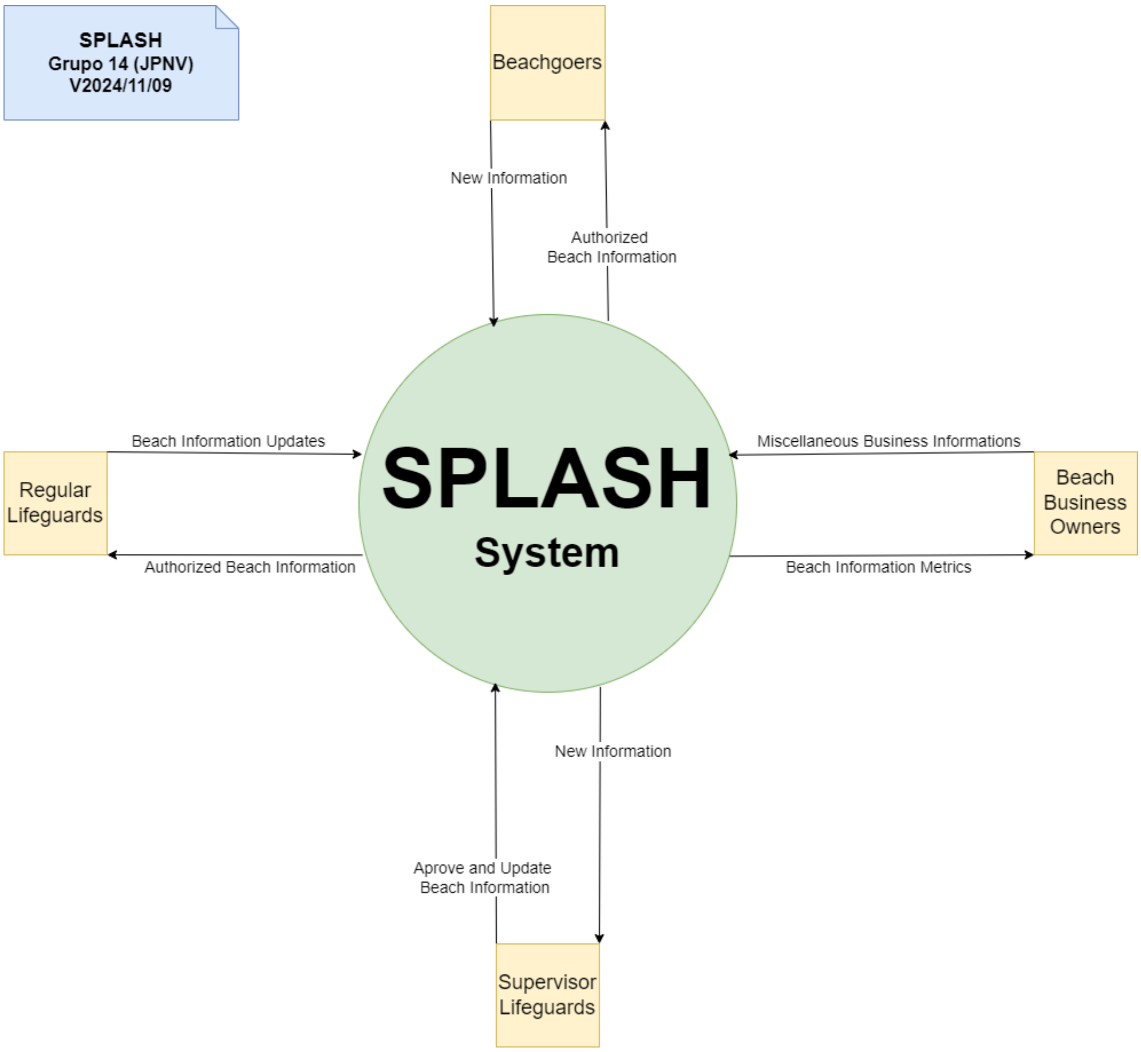


Figure 6.1: SPLASH System Context Diagram: For a detailed, full-resolution version, visit: `https://github.com/SPLASHub/SplashDocumentation/`

6.2 High-Level Architecture Diagram

Figure 6.2 illustrates the system's core architectural layers: the Presentation Layer and each interface, the Program Logic Layer and the Data Layer with persistent data storage. The diagram depicts flow of requests and responses between users, interface components, backend modules, and the database. This design allows for easy future updates and growth (scalability), allowing new features and components to be integrated smoothly as the system evolves.

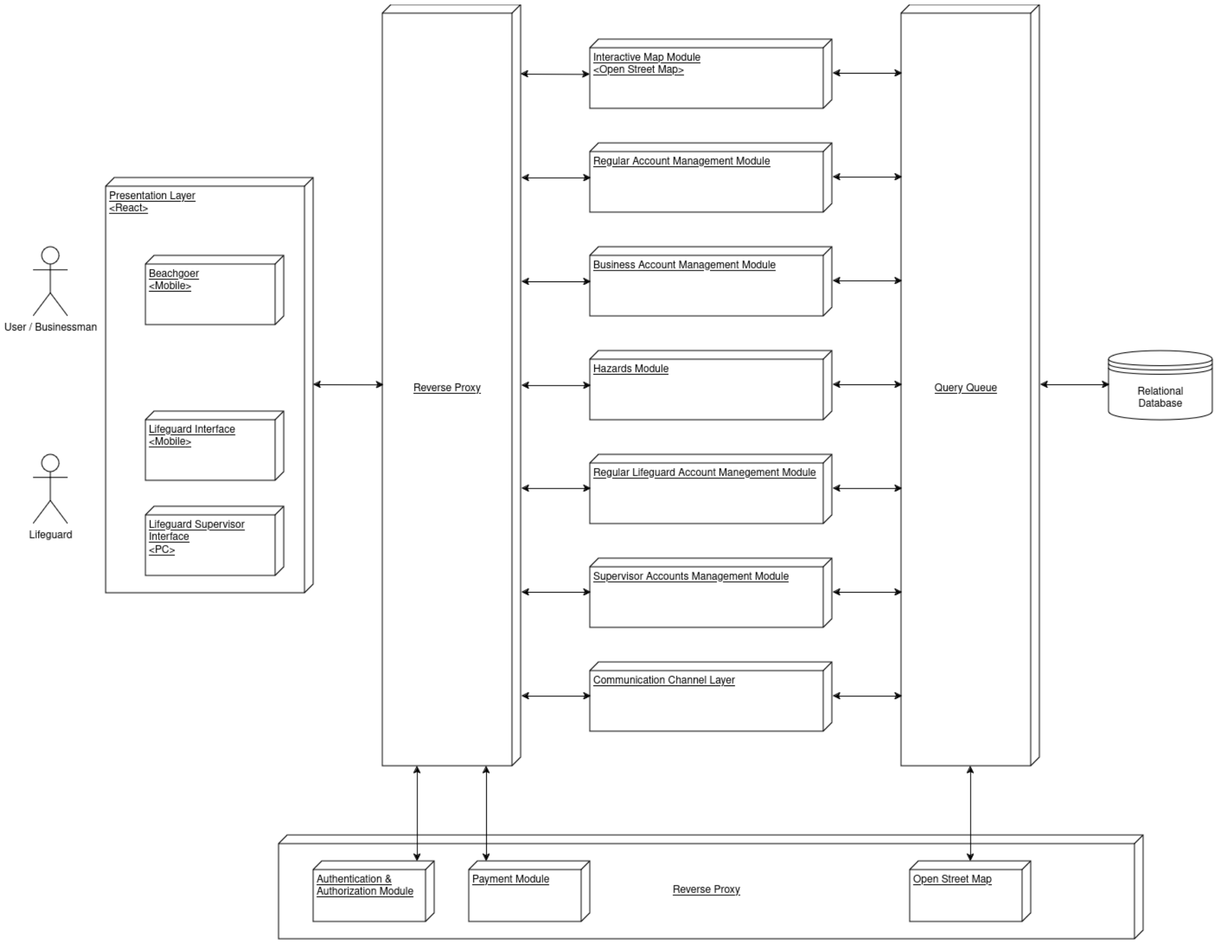


Figure 6.2: SPLASH High-Level Architecture Diagram: For a detailed, full-resolution version, visit: `https://github.com/SPLASHub/SplashDocumentation/`

6.3 Use-Case Diagram

The use-case diagram (Figure 6.3) illustrates the main actors and their interactions with the SPLASH system. Regular users, lifeguards, supervisors and beach business owners each access different features, such as reporting hazards, managing teams, viewing beach information, and inputting data. External services handle authentication and payments. The diagram highlights how each actor accesses relevant system functions, with clear boundaries and relationships between use cases.

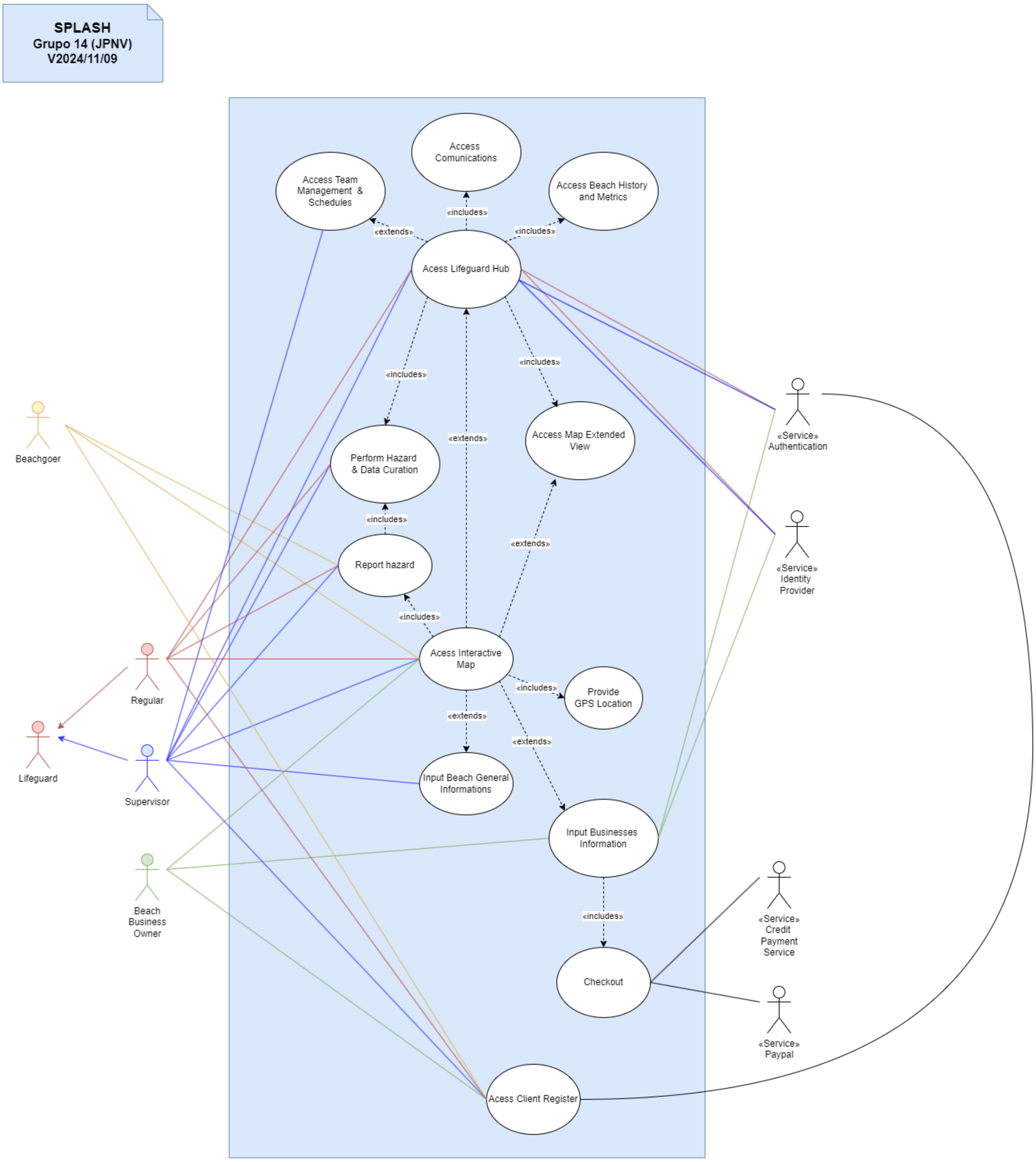


Figure 6.3: SPLASH: System Use-Case Diagram: For a detailed, full-resolution version, visit: `https://github.com/SPLASHub/SplashDocumentation/`

6.4 Components Diagram

The system components diagram (Figure 6.4) shows the main architectural elements of the SPLASH system and their interactions. Wearable tracking devices with GPS and RFID modules communicate with the backend server through an API. The backend server manages data storage and retrieval via a connected database. Users interact with the system through web app interfaces, which are tailored for lifeguards, beachgoers and businesses, ensuring each role accesses the appropriate features.

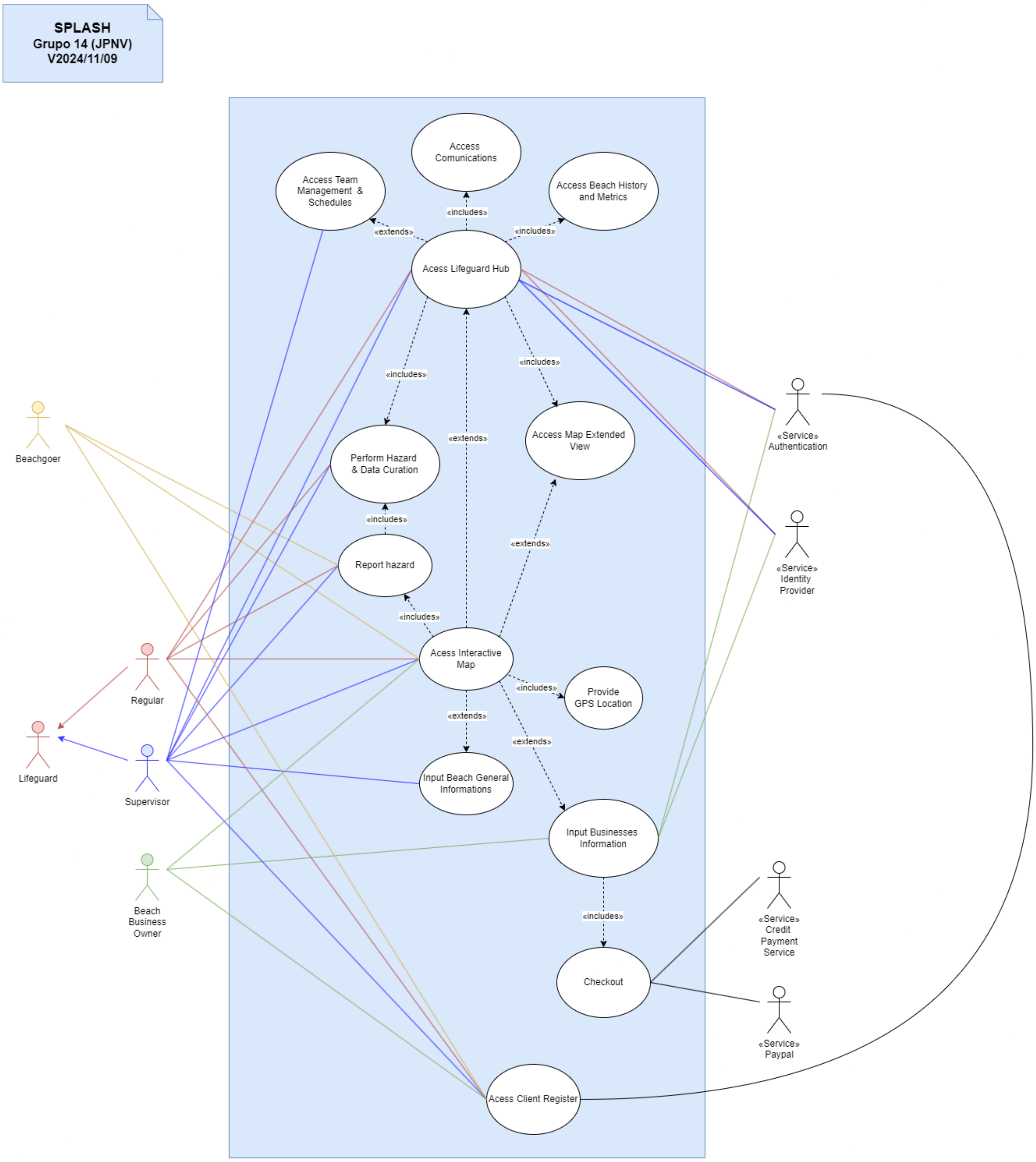


Figure 6.4: SPLASH: System Components Diagram: For a detailed, full-resolution version, visit: `https://github.com/SPLASHub/SplashDocumentation/`

6.5 Data Flow Diagram

The data flow diagram (Figure 6.5) provides an overview of how information moves through the SPLASH system. It details the interactions between key external entities (users, lifeguards, etc...) and the system's main processes, including hazard reporting, team management, beach information access, and payment handling. The diagram illustrates how data is collected, processed, stored, and shared across different modules.

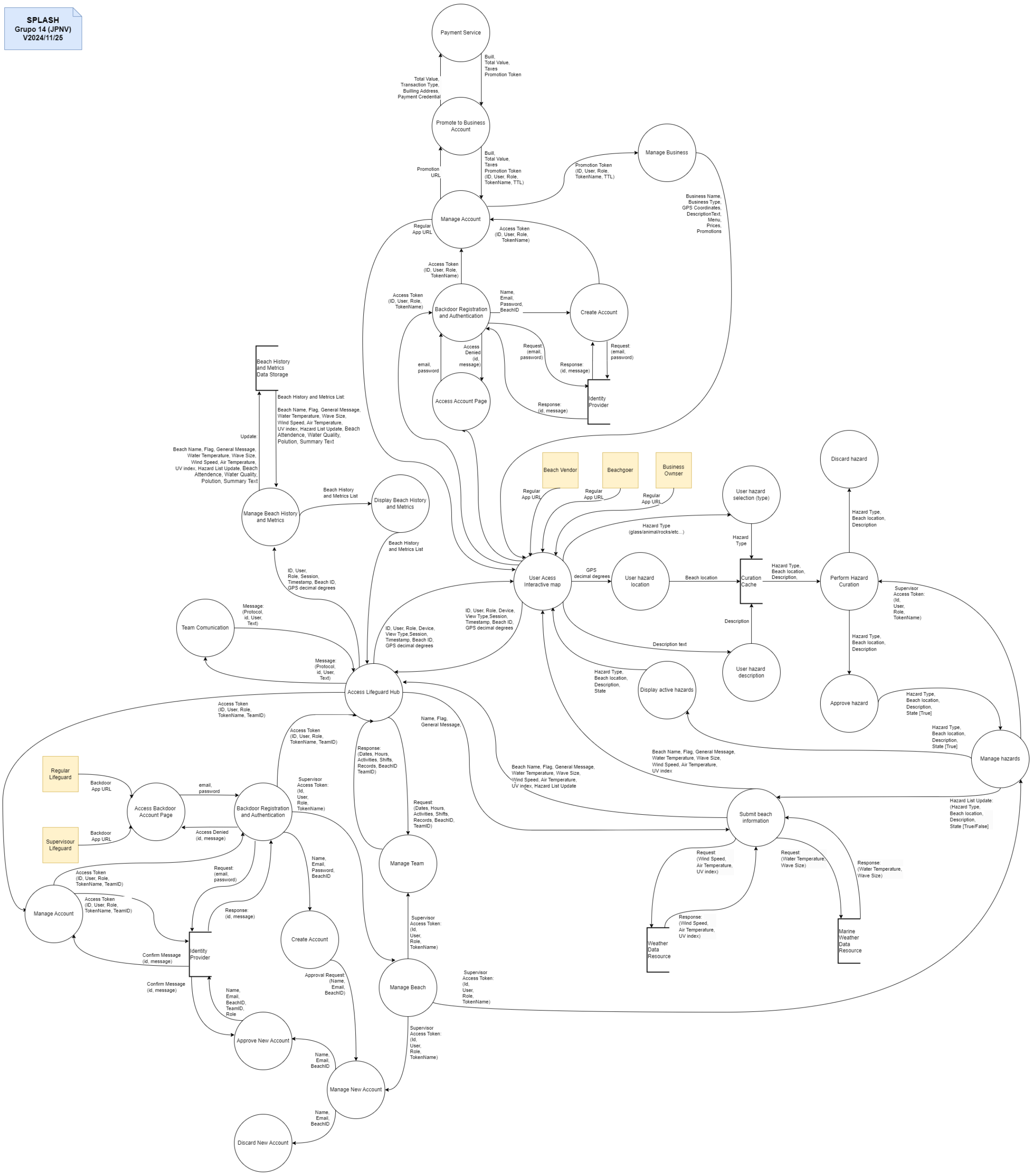


Figure 6.5: SPLASH: System Data Flow Diagram: For a detailed, full-resolution version, visit: `https://github.com/SPLASHub/SplashDocumentation/`

6.6 Deployment Diagram

Figure 6.6 illustrates the deployment architecture of the SPLASH system, showcasing the interaction between different hardware and software components in a real-world environment.

The system consists of three primary components:

- **Wearable Device**: Equipped with GPS/RFID tracking capabilities, this device communicates wirelessly with the backend server to provide location and tracking data.
- **User Devices**: These include web-based interfaces. These devices communicate with the backend server using REST APIs or WebSocket protocols.
- **Backend Server**: Hosts multiple services, including an API Service for handling requests, a Notifications Engine for managing alerts, and a Device Management module. The backend server interacts with an SQL database to store and retrieve relevant data using standard protocols.

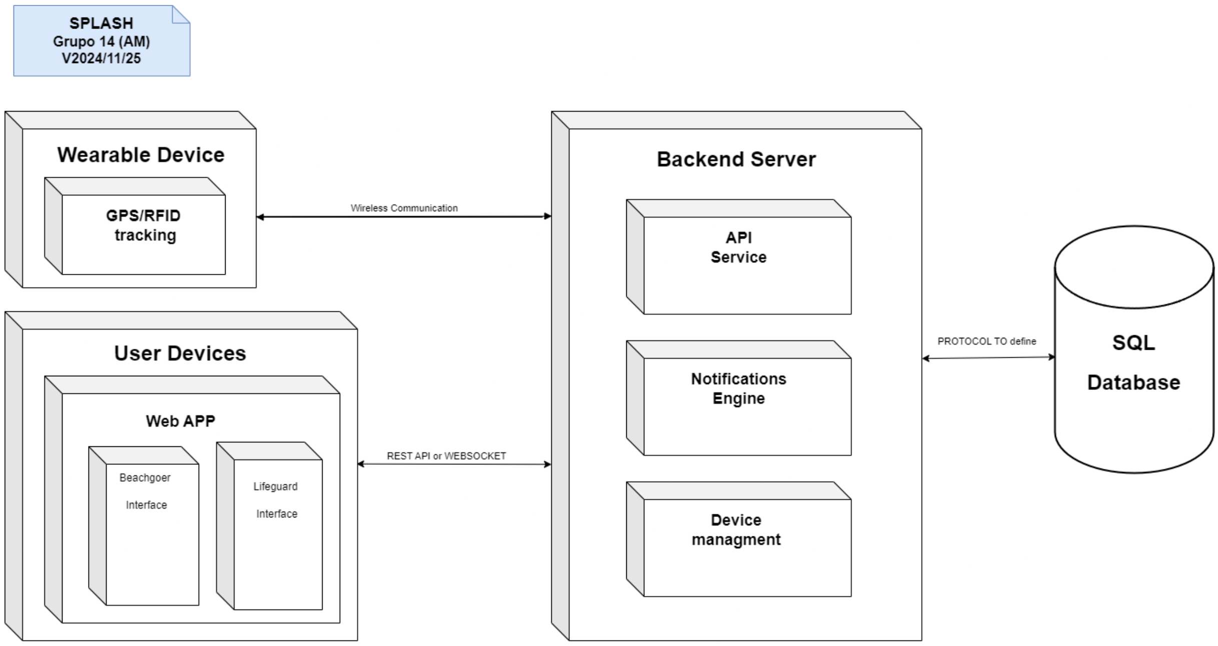


Figure 6.6: SPLASH: System Deployment Diagram: For a more detailed view: `https://github.com/SPLASHub/SplashDocumentation/`

6.7 General Architecture Diagram

Figure 6.7 provides a comprehensive overview of the SPLASH system architecture. It integrates all functional modules and services into a single schematic.

Key components include:

- **Authentication & Authorization Module**: Manages user access roles and account provisioning, ensuring secure access to the system.
- **Tracking Services**: Utilizes RFID and GPS to provide real-time location data for users and devices.
- **Interactive Map Module**: Integrates OpenStreetMap for visualization, allowing users to interact with geographic data.
- **Payment Module**: Supports transaction processing and account upgrades.
- **Presentation Views Layer**: Offers tailored interfaces for different user roles—Lifeguards, Supervisors, and Regular Users—with optimized map views and tool access.
- **Reverse Proxy**: Acts as the central routing mechanism that coordinates requests and responses between the view layer and backend services.
- **Query Queue & Scalable Database**: Ensures efficient processing and persistent storage of requests and data through a queued system architecture.

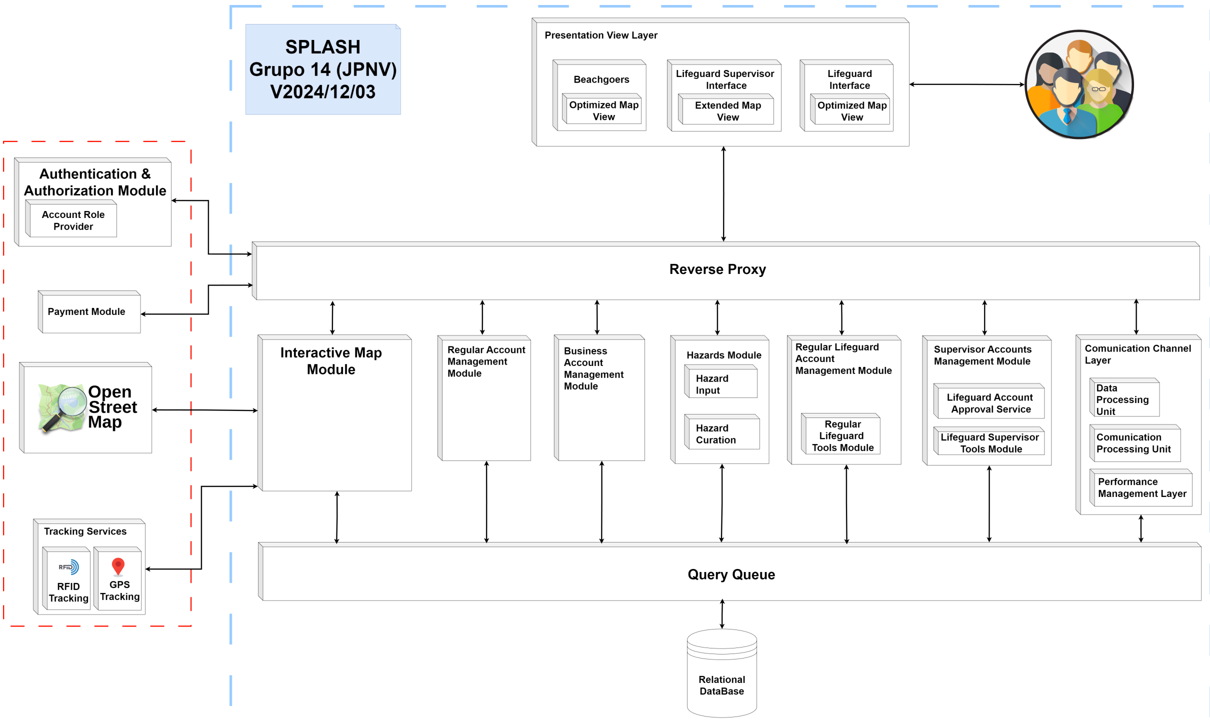


Figure 6.7: SPLASH: System General Architecture Diagram: For a more detailed view: https://github.com/SPLASHub/SplashDocumentation/

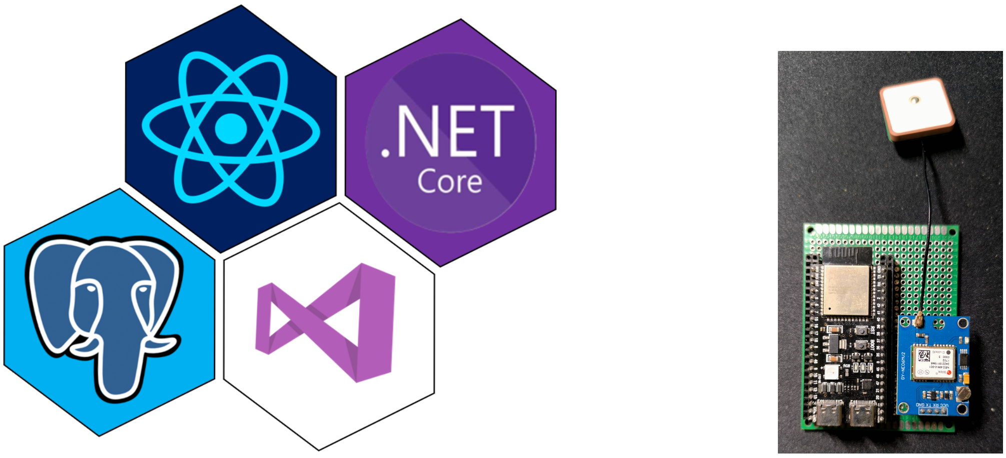
6.8 Selected Technologies and Implementation

Following the development of the previous architectural diagrams and team discussions, a set of modern technologies was selected to implement the SPLASH system. The system architecture was designed as a web-based solution, integrating both hardware and software components for effective user interaction.
The **frontend** of the application was developed using **React**, chosen for its flexibility, reusable component structure, and ability to build dynamic and responsive user interfaces.
For the **backend**, **Visual Studio 2022** was employed to develop a RESTful API using **C# and .NET**, which served as the bridge between the frontend, database, and wearable devices. This environment was selected for its robustness, development efficiency, and strong integration with cloud services.
A **relational database** was implemented using **PostgreSQL**, selected for its reliability, scalability, and ability to efficiently manage structured data and complex relationships between entities.

The **wearable devices**, developed as wristband prototypes specifically for children, integrate multiple technologies to ensure secure and reliable tracking. The core purpose of these devices is to provide real-time **geolocation data** exclusively to the legal guardians of the child, ensuring both safety and privacy. Each wristband prototype is built around the **ESP32-S3-WROOM-1** microcontroller, programmed using **PlatformIO** with the **ESP-IDF** framework. This microcontroller offers a powerful and energy-efficient solution for embedded IoT systems. For location tracking, the wristbands are equipped with a **NEO-6M GPS sensor**, enabling accurate and continuous geolocation updates. Communication with external devices is handled via the **Web Bluetooth API**, which allows for direct browser-based interaction without the need for native applications.

Finally, the entire system was deployed and hosted on the **Microsoft Azure** cloud platform. Azure was chosen for its scalability, reliability, and seamless support for .NET applications, ensuring that the system remains accessible and operational under varying loads.

This technology stack ensures that the SPLASH solution is robust, scalable, and user-centric, addressing the project's core objectives while leveraging modern development practices to enhance safety, usability, and performance.



(a) Selected Technologies for development

(b) GPS wristband prototype

Figure 6.8: Overview of selected technologies and the prototype for the GPS wristband

6.9 Database Design

The SPLASH project employs a relational database management system (Database Management System (DBMS)) as its core data infrastructure. This ensures structured, efficient, and scalable data storage, retrieval, and management to support the platform's functionalities. The database is designed to maintain data integrity while allowing extensibility to support future enhancements and additional data sources such as smart devices.
The schema mirrors real-world entities involved in lifeguard operations, beach environments, and hazard management. Each table is uniquely identified using primary keys, while relationships between entities—such as users, lifeguards, beaches, and hazards are modeled using foreign keys, as illustrated in the Entity Relationship Diagram (Figure 6.9). This normalization focused design reduces redundancy, mitigates data anomalies, and allows easy data maintenance.

6.9.1 Entity Relationship Diagram

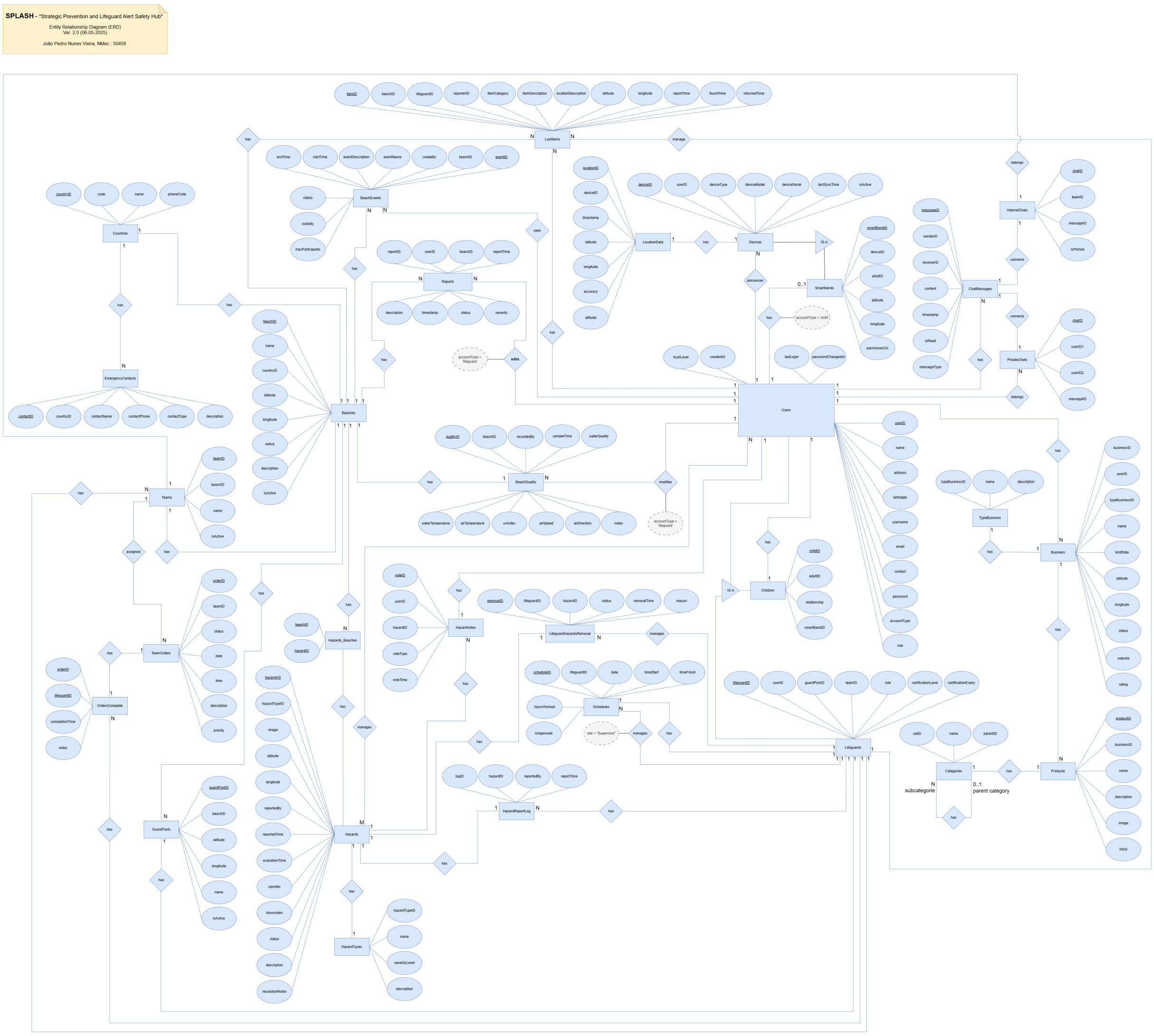


Figure 6.9: SPLASH: Entity Relationship Diagram: The diagram presents the conceptual overview of the main entities and their relationships, laying the foundation for the database structure. For a more detailed view: `https://github.com/SPLASHub/SplashDocumentation/`

The Entity Relationship Diagram (ERD) presents all the key entities and their relationships within the SPLASH operational ecosystem. These include core actors such as `Users`, `Lifeguards`, and `Children`, as well as contextual elements like `Beaches`, `GuardPosts`, `Hazards`, and `Schedules`. Relationships are clearly defined, including one-to-many (e.g., a country has many beaches), many-to-many (e.g., hazards can affect multiple beaches and vice versa through the `Hazards_Beaches` table), and associative entities (e.g., `TeamOrders`, `LifeguardHazardRemoval`).

Conclusion: A detailed review of the database design confirms that the ERD is normalized up to Third Normal Form (3NF), as:

- Each attribute is atomic and functionally dependent on the entire primary key (1NF).
- There are no partial dependencies in any composite primary keys (2NF).
- There are no transitive dependencies between non-key attributes (3NF).

6.9.2 Relational Schema

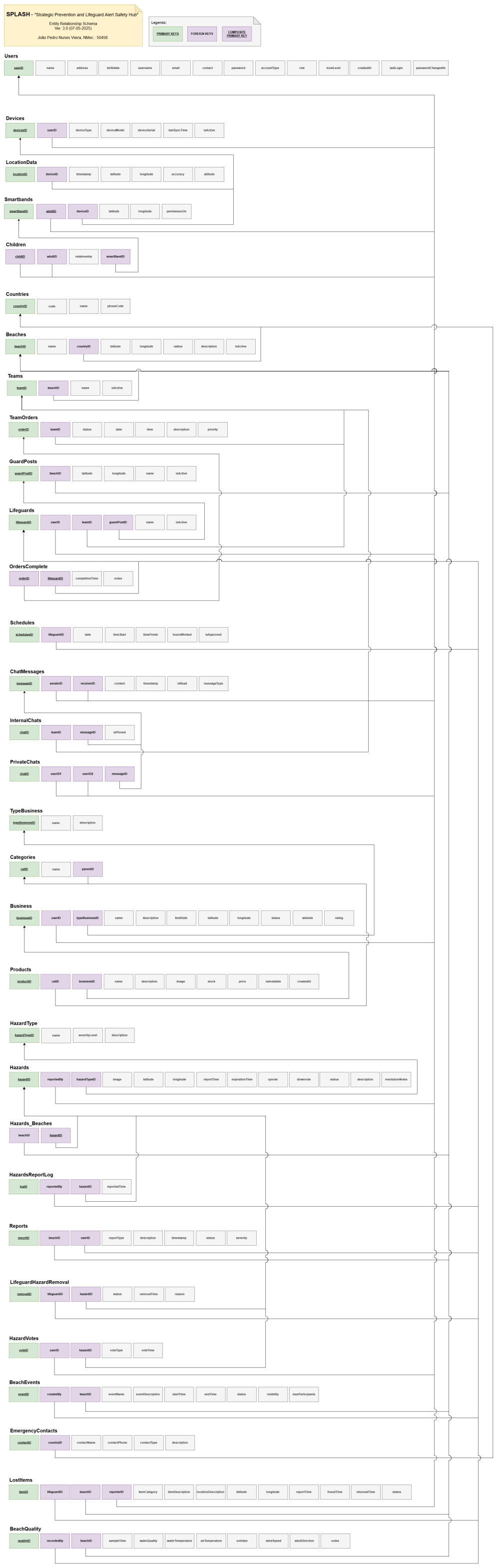


Figure 6.10: SPLASH: Relational Schema. The schema translates the conceptual design into implementation-ready tables, complete with primary keys, foreign keys, and all necessary fields to support data integrity. For a more detailed view: `https://github.com/SPLASHub/SplashDocumentation/`

The relational schema provides a detailed logical blueprint for the implementation of the SPLASH database. Each table reflects a real-world entity and its attributes, and the schema incorporates comprehensive relationship mapping.

Normalization and Integrity:

- Each table has a clearly defined primary key (e.g., `userID`, `hazardID`, `beachID`).
- Foreign keys enforce data consistency across related tables.
- Constraints such as `NOT NULL`, `UNIQUE`, and `CHECK` maintain the validity of data inputs.
- Attribute domains are defined with appropriate data types.
- No computed or derived fields are stored, in accordance with normalization principles.

Performance and Optimization:

- Indexes are applied to fields used in joins and search conditions (e.g., foreign keys and commonly queried attributes).
- The schema allows for horizontal scaling (e.g. new rows) and vertical scaling (new columns or tables) without major structural revisions.

Extensibility: The modular and relational design enables future integrations with minimal disruption:

- Additional smart devices can be added via the `Devices` or `Smartbands` tables.
- New user roles (e.g., medical responders, volunteers) can be appended by extending the `Users` entity and its relations.
- New environmental or safety data sources can be accommodated by expanding the `Hazards` or `LocationData` tables.

6.9.3 SmartBand firmware

The bracelet's firmware implements a tightly choreographed startup sequence and task-based runtime architecture on the ESP32-S3-WROOM-1 using the ESP-IDF framework and FreeRTOS. Upon power-up, the firmware first brings up the BLE stack in peripheral role by initializing the NimBLE host and controller, configuring Generic Access Profile (GAP) parameters—such as the device name "SPLASH_BRACELET" and a 100 ms advertising interval—and registering a primary GATT profile. The GATT server then defines a Location and Speed service exposing two notifiable characteristics: a UTF-8 string carrying latitude and longitude in decimal degrees and a little-endian 32-bit integer representing speed in centimetres per second.

With BLE advertising active, the application configures two UART ports at 115 200 baud (UART1 for the u-blox NEO-6M GPS module and UART2 for debug output) by installing interrupt-driven receive buffers and spawning the GPS_UART_Task. Immediately thereafter, the firmware programs the GPS module for a 5 Hz update rate and optimized hot-start sensitivity by transmitting a sequence of u-blox Binary Protocol (UBX)-formatted configuration frames over UART1. These commands enable only the Global Positioning System Fix Data (NMEA sentence) (GGA) and Recommended Minimum Navigation Information (NMEA sentence) (RMC) National Marine Electronics Association (NMEA) sentences, reducing downstream parsing load.

FreeRTOS then schedules the radio, host and GATT subtasks alongside two application tasks. The GPS task blocks on incoming bytes from UART1, aggregates complete NMEA frames and hands them to the parser module, which validates checksums, fragments sentences and extracts fix data—latitude, longitude, UTC time, satellite count and speed. Parsed values write into a mutex-protected data structure, and each valid RMC sentence triggers an event flag. The BLE task waits on this event, then calls the GATT update functions to write the new coordinate and speed values and issue notifications to any connected central device. Both tasks log errors via the ESP32 logging Application Programming Interface (API) and, in the case of transient faults, retry after a brief non-blocking delay, ensuring the scheduler remains responsive.

By decoupling BLE and GPS workflows into independent, event-driven tasks, the firmware ensures that sensor polling, message parsing and radio event handling proceed concurrently without interference. The resulting data flow—from satellite signals to UART, through NMEA parsing into application state, and onward via GATT notifications to a central client—runs at a steady five updates per second with sub-meter precision, all while drawing only milliamperes during active operation. This design satisfies the SPLASH ecosystem's requirements for low-power, high-responsiveness child-tracking devices.

6.9.4 Conclusion

The SPLASH database design effectively balances real-world complexity with relational efficiency. Both the ERD and the implemented schema reflect strong adherence to database normalization principles, particularly up to Third Normal Form (3NF). The structure ensures minimal redundancy, optimized performance, and maintainability, while remaining adaptable.

CHAPTER 7

Usability Evaluation

To ensure the SPLASH system aligns with user needs and expectations, a usability evaluation was conducted during the Construction phase using low-fidelity prototypes, as described in Chapter 5. This evaluation aimed to identify usability issues early and to guide design decisions for the subsequent development stages.

7.1 Methods

7.1.1 Wizard of Oz Approach

The Wizard of Oz technique was employed to simulate system functionalities without full implementation. During testing, participants interacted with interfaces as though they were functional, while the underlying responses were manually controlled by a facilitator. This method enabled the team to evaluate user behavior and expectations in a realistic yet controlled manner.

7.1.2 Usability Testing Procedure

- **Participants:** Five users participated in the usability evaluation. They were selected to represent the primary personas defined in Chapter4**??**, including lifeguard supervisors, regular lifeguards, beachgoers, and business owners.
- **Tasks:** Participants were asked to complete scenario-based tasks derived from their respective personas, such as locating lifeguard stations, signaling hazards, managing schedules, and requesting assistance. These tasks were grounded in real use cases identified during the requirements and task analysis stages.
- **Think-Aloud Protocol:** Participants were encouraged to verbalize their thoughts while performing tasks, allowing the facilitators to gain insights into user expectations, reasoning processes, and usability challenges.
- **Observation and Note-Taking:** The research team recorded user interactions, behavioral patterns, and errors during testing sessions, supported by photographs (e.g., Figure 7.2).

- **Post-Test Feedback:** Following the tasks, participants provided qualitative feedback through brief interviews and completed a System Usability Scale (SUS) questionnaire to quantify the overall usability of the prototype.

All participants signed an informed consent document before the evaluation and were informed that they could stop the session at any time without justification.

7.2 Evaluation Objective

The primary goal of this evaluation was to validate whether the SPLASH prototype could achieve a SUS score of at least 70, a widely accepted threshold for acceptable usability in interactive systems. This metric was also defined as a success criterion for the project.

7.3 Results and Insights

The average SUS score obtained across all participants was **77.5**(see Figure 7.1), meeting the defined usability goal. The evaluation also revealed the following:

- **Strengths:** Participants praised the clarity of the interactive map, the perceived usefulness of hazard alerts, and the logical task flows for reporting and requesting assistance.
- **Usability Issues:** Some users experienced initial confusion when accessing the schedule management features and interpreting certain map symbols.
- **Suggestions:** Users suggested visual improvements (e.g., color contrast), more explicit icons for dangerous areas, and tooltips for new users unfamiliar with the interface.
- **General Feedback:** Participants reported a high level of satisfaction with the system's potential impact on beach safety, particularly the real-time information and GPS bracelet integration.

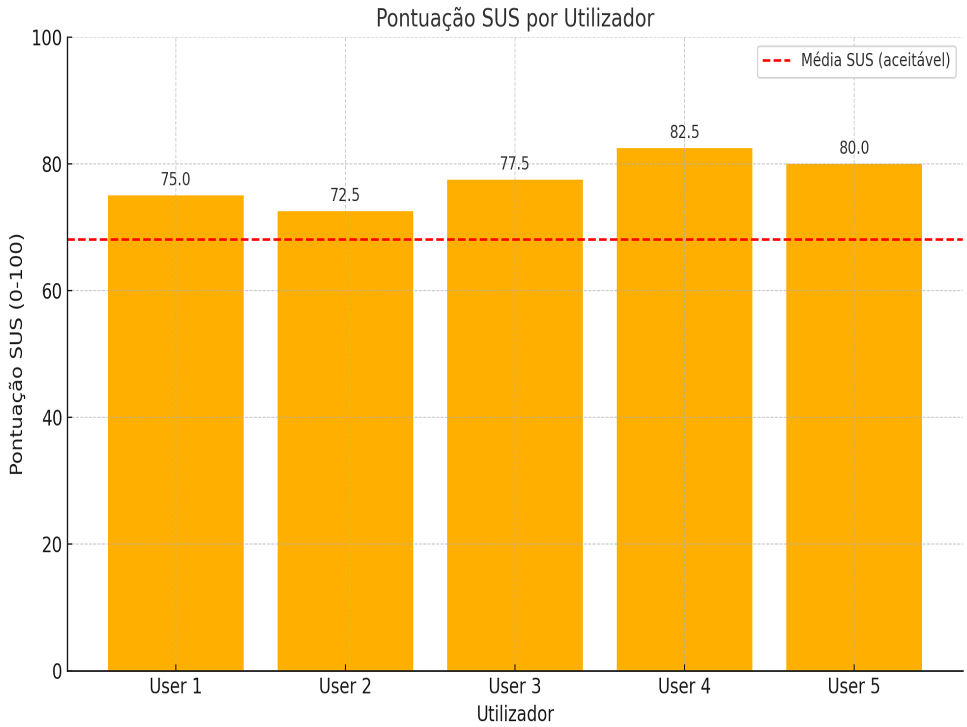


Figure 7.1: SPLASH: SUS score

7.4 Summary

The usability evaluation provided critical insights into the prototype's effectiveness, revealing both its strengths and improvement areas. The methodology, combining the Wizard of Oz technique with structured testing, proved successful in simulating real-world interactions. The SPLASH system met its usability benchmark, supporting its viability as a user-centered digital solution for coastal safety management.

Figure 7.2: SPLASH: Photograph captured during a usability testing session with users

CHAPTER 8

Implementation and Iterative Usability Testing

The implementation phase of SPLASH involved translating the prototypes and data models into functional web applications. This phase was guided by a user-centered design approach, where iterative usability testing played a central role. As such, development was conducted in parallel with structured evaluation cycles, allowing continuous refinement of the interface and functionalities based on real-world user feedback.

8.1 Application Architecture

To address the distinct contexts and requirements of the primary user groups, two separate web applications were developed:

- **SPLASH Lifeguard Application**: Designed for lifeguards and supervisors, this application supports core operational tasks such as:
  - Team and shift scheduling;
  - Hazard reporting and resolution;
  - Real-time alerts and notifications;
  - GPS-based tracking of beachgoers using smartbands;
  - Access to beach history and performance metrics.
- **SPLASH Beachgoer Application**: A public-facing interface optimized for mobile use, aimed at enhancing beach safety awareness and user autonomy. Key features include:
  - Interactive map with live hazard zones;
  - Reporting hazards directly from the beach;
  - Access to flag status, weather updates, and UV index;
  - Information on beach amenities and business locations;
  - Integration with QR codes placed on-site.

Both applications communicate with a centralized backend service and relational database (see Chapter 6), ensuring data consistency, real-time synchronization, and secure access control across roles.

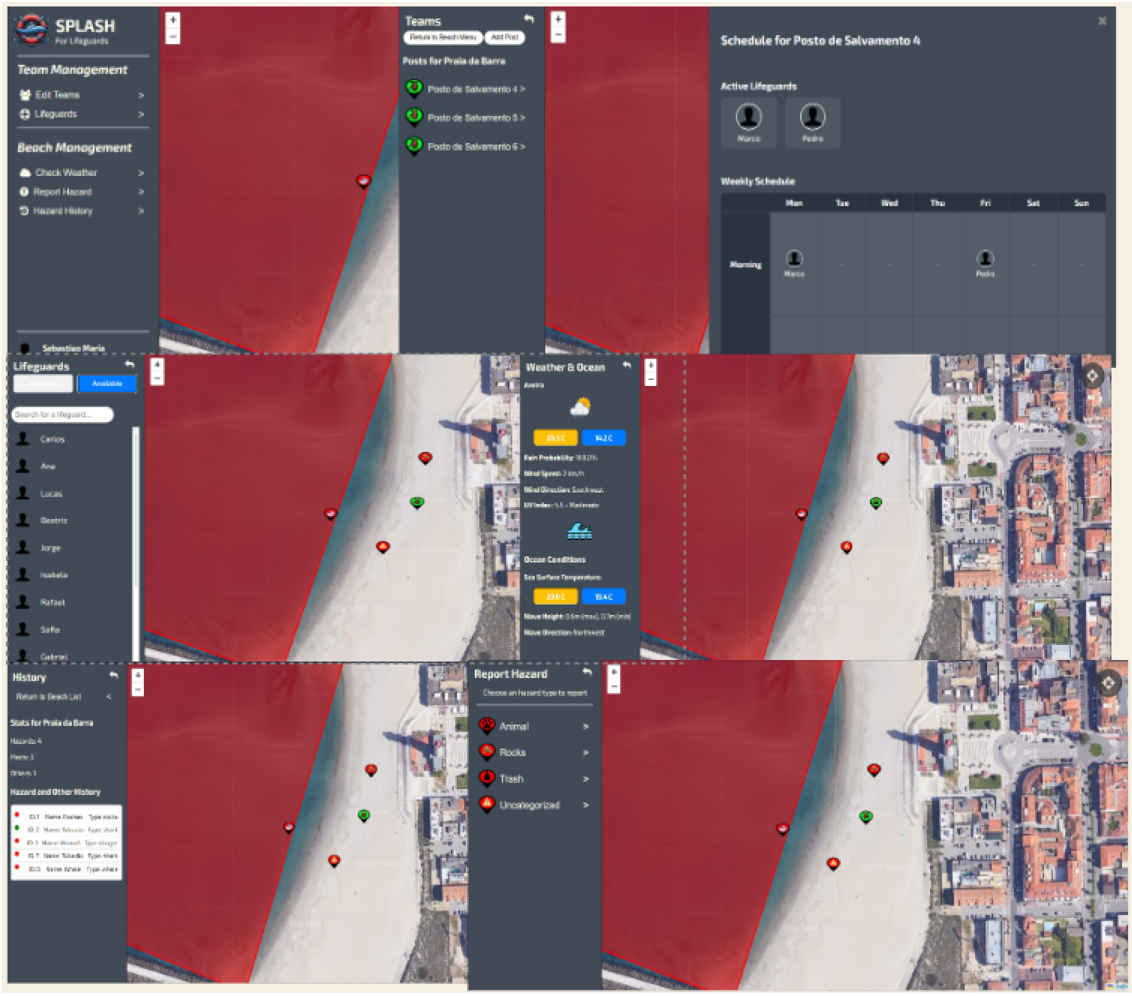


Figure 8.1: SPLASH Web Interface

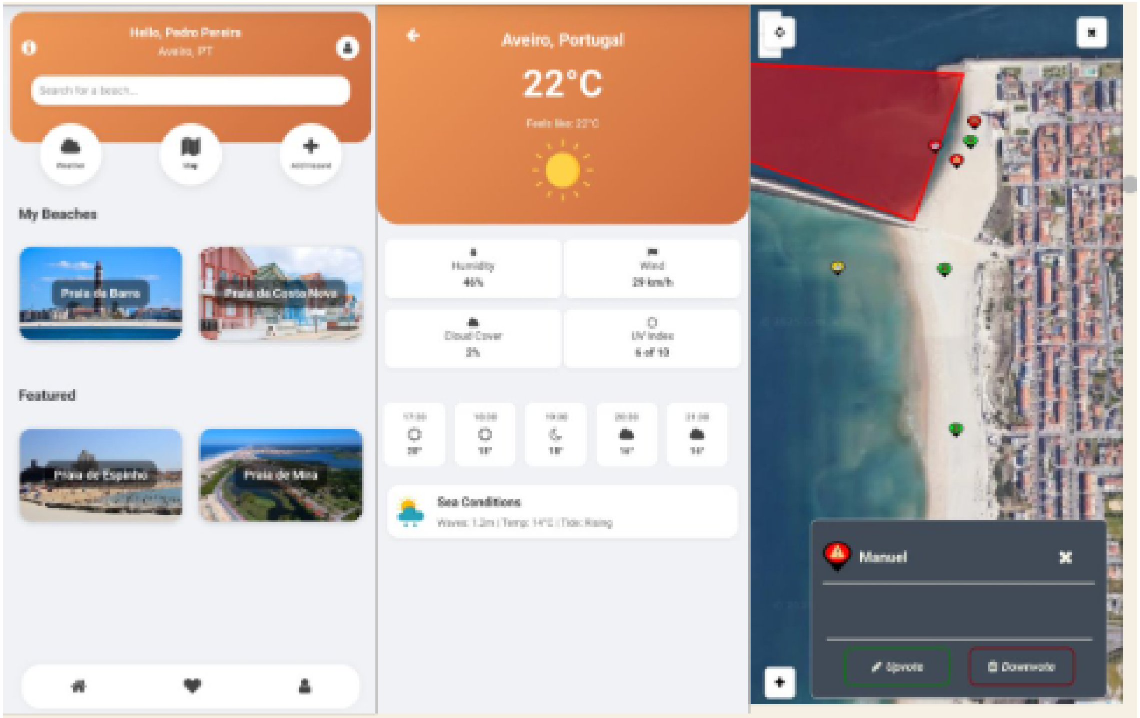


Figure 8.2: SPLASH Beachgoer Web Interface

8.2 Implementation Process

The development followed an agile and incremental approach, allowing the integration of feedback loops after each testing phase. Initial mockups and user flows were implemented using ReactJS for the frontend and Node.js/Express for the backend services. Data was stored in a PostgreSQL database designed according to the relational schema presented earlier.

Security measures were implemented to protect personal and location data, complying with privacy and ethical guidelines, particularly regarding GPS tracking and emergency notifications.

8.3 Iterative Usability Testing

Following the initial Wizard of Oz evaluation (Chapter 7), two subsequent rounds of usability testing were conducted with improved prototypes:

8.3.1 Post-Implementation Test Plan

- **Participants:** Five individuals from the original pool were re-invited to test the functional prototypes, ensuring continuity in feedback. The profiles again covered all main personas.
- **Test Scenarios:** Tasks were aligned with real-world workflows, such as initiating an emergency response, updating flag status, reporting broken glass, or scheduling lifeguard shifts.
- **Methodology:**

  - Remote and on-site testing, depending on user availability;
  - Observation and logging of task performance;
  - Post-test interview;
  - Completion of a SUS (System Usability Scale) questionnaire.

8.3.2 Key Outcomes

- **SUS Score:** The final version of the system reached a SUS score of **70%**, meeting the project's usability benchmark.
- **Positive Feedback:** Users appreciated the clarity of the interface, responsiveness on mobile devices, and usefulness of real-time alerts.
- **Identified Issues:** Some icons and color contrasts were unclear under strong sunlight conditions. Additionally, the hazard drawing tool needed simplification.
- **Improvements Implemented:**
  - Replaced hazard icons with more intuitive symbols;
  - Increased UI contrast for sun readability;
  - Added onboarding tooltips for new users.

8.4 Summary

The implementation of SPLASH combined technical development with iterative usability testing, ensuring that the system evolved in direct response to user needs. The dual-application model proved effective in serving both lifeguards and beachgoers, and the final system met its usability goal, demonstrating functional maturity and user-centered design alignment.

CHAPTER 9

Results & Discussion

The evaluation of the SPLASH system demonstrates a solid alignment between the technical implementation and the real needs of its end users. Both quantitative and qualitative analyses suggest that the system fulfills its usability goals and provides a strong foundation for future iterations. Moreover, the results highlight how a user-centered design approach—combined with targeted technological features—can improve operational efficiency and safety in coastal environments.

9.1 Achievement of Usability Goals

A core objective of the SPLASH project was to deliver an intuitive and effective interface for diverse user groups. The system achieved a System Usability Scale (SUS) score of 77%, exceeding the target threshold of 70%, and confirming the following points:

- The iterative, user-centered design process successfully incorporated feedback from key stakeholders, including lifeguards, beachgoers, and business owners.
- The interface proved intuitive and accessible across all user profiles, supporting a wide range of tasks from hazard reporting to real-time monitoring and team coordination.

These results indicate that the SPLASH system is not only usable, but also well-received by its intended audience, establishing a strong baseline for potential real-world deployment.

9.2 Key Findings from Usability Tests

The usability testing process uncovered several strengths of the system, validating many of the design decisions made throughout the project:

- **Interactive Map Functionality**: Participants praised the clarity and usefulness of the interactive map, especially in visualizing:
  - Real-time environmental data (e.g., weather, tides)
  - Hazard zones and incident reports

    - Lifeguard and resource positions

  This functionality was central to decision-making and increased situational awareness for all users.

- **Alert and Notification Systems**: The system's notification framework—including GPS-based alerts, lost child tracking, and real-time hazard warnings—was consistently identified as critical by test participants. These features provided:
    - Immediate, actionable feedback to both lifeguards and beachgoers
    - A sense of security and control, especially for guardians and supervisors
- **Data Integration and Historical Analysis**: The inclusion of historical incident data and beach metrics allowed users—particularly supervisors—to:
    - Identify high-risk areas and trends
    - Improve planning and preventive strategies
    - Justify resource allocation based on past data

  This proved especially valuable for lifeguard coordinators and decision-makers.

Overall, the tests reinforced the importance of combining real-time data with historical insights and intuitive user interactions. The system was recognized as a valuable tool not only for emergency response, but also for enhancing day-to-day beach management and communication.

CHAPTER 10

Future Work and Contributions

Although the SPLASH system achieved its initial objectives and demonstrated high usability, there are several directions in which the platform can be further developed and improved. These enhancements are essential to increase the system's robustness, scalability, and overall value to its various stakeholders.

10.1 Proposed Future Enhancements

10.1.1 Real-Time Messaging System

One of the most impactful additions to the SPLASH platform would be the implementation of a dedicated messaging system, enabling real-time communication between lifeguards, supervisors, and potentially beachgoers. This feature would streamline coordination, facilitate the rapid exchange of information during emergencies, and reduce the reliance on external communication tools (e.g., radios or mobile phones). Key capabilities could include:

- Private and group chat channels for lifeguard teams
- Priority tagging for critical messages (e.g., emergency alerts)
- Integrated notification system linked to the interactive map

10.1.2 Dedicated System for Field Lifeguards

The current proof of concept already supports supervisory roles and coordination tasks; however, a dedicated and optimized interface for lifeguards operating directly on the beach would further enhance usability in the field. This system should prioritize minimal interaction time, fast access to incident reports, and simplified tools for:

- Confirming or dismissing hazard alerts
- Accessing shift schedules and team assignments
- Logging incidents and responding to GPS-based alerts

Additionally, such a system could be implemented as a progressive web app or mobile application to ensure compatibility with tablets or smartwatches.

10.1.3 Expanded Functionality for Beachgoers

While the current system offers beachgoers access to hazard information and basic alerts, additional features could increase engagement, safety, and satisfaction. Potential enhancements include:

- Personalized risk notifications based on location and behavior
- Expanded beach service directory with filters and reviews
- Gamified safety challenges or educational prompts
- Real-time feedback channels for reporting issues or suggestions

These improvements would support a more participatory safety ecosystem and encourage responsible behavior among beach users.

10.2 Broader Contributions

Beyond its technical achievements, the SPLASH project offers broader contributions to coastal safety and digital public services:

- **Scalable Architecture**: The system's modular design supports future expansion to new beaches, municipalities, or even international contexts.
- **User-Centered Methodology**: The project reinforces the value of participatory design in public safety systems, particularly in high-stakes environments such as coastal surveillance.
- **Educational Impact**: The project has increased awareness around coastal hazards and the operational challenges faced by lifeguards, highlighting opportunities for innovation in public safety infrastructure.

10.3 Conclusion

The SPLASH platform provides a strong foundation for improving beach safety through technology. However, its long-term success depends on continuous improvement, stakeholder collaboration, and the adoption of advanced features that address the evolving needs of lifeguards and beachgoers alike. The future work outlined in this chapter represents the next logical step in transforming SPLASH from a proof of concept into a comprehensive operational solution.

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APPENDIX A

Additional content

.1 Hierarchical Task Analysis for the SPLASH Web App

Figure .1: Complete Hierarchical Task Analysis diagram for the SPLASH web application.

Teste com utilizadores

Teste Nº1 - PC:

Neste teste nº1 vai ser exposto a um programa (protótipo). Faça as seguintes tarefas por ordem. Em caso de dúvida pode pedir ajuda. As suas ações contribuem para a correção e aperfeiçoamento *do programa e erros existente. ATENÇÃO: Por ser um protótipo, este programa pode ter bugs, pelo que não se sinta frustrado, triste ou zangado por quaisquer tarefas que não consiga realizar. A qualquer momento pode desistir de uma tarefa ou até mesmo do próprio teste ou testes.*

Cenário: *Você é um Nadador-Salvador Supervisor.*
Use o programa, vigie a praia e coordene a sua equipa. Boa Sorte!

Tarefa 1	*[Efetue o Login]* ------------------------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 2	*[Aceder ao Perfil de Utilizador]* ------------------------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 3	*[Aceder à secção de Gestão de Equipa]* ------------------------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 4	*[Aceitar o registo de um novo membro da sua equipa]* ------------------------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 5	*[Recebeu um alerta de perigo no mapa! Clique neste e envie um membro da sua equipa para verificação]* ------------------------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 6	*[Aceda as câmaras de vigilância]* ------------------------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 7	*[Alerta de pré-afogamento na câmara! Envie um membro da sua equipa]* ------------------------------ Nada Fácil 1 2 3 4 5 Muito Fácil

Figure .2: Page 1 – Usability Tests for Lifeguard Supervisors

Tarefa 8	*[Verifique as condições atmosféricas da praia]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 9	*[Altere a bandeira hasteada para Verde]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 10	*[Aceda ao menu "Histórico e Métricas" da praia]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 11	*[Altere agora o horário da sua colega "Joana Costa".]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 12	*[Envie mensagem a um colega]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 13	*[Termine o seu turno]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Figure .3: Page 2 – Usability Tests for Lifeguard Supervisors

.2.1 Usability Tests: Regular Lifeguard

Teste com utilizadores

Teste N°1 – Smartphone ou Tablet:

Neste teste nº1 vai ser exposto a um programa (protótipo). Faça as seguintes tarefas por ordem. Em caso de dúvida pode pedir ajuda. As suas ações contribuem para a correção e aperfeiçoamento do programa e erros existente. ATENÇÃO: Por ser um protótipo, este programa pode ter bugs, pelo que não se sinta frustrado, triste ou zangado por quaisquer tarefas que não consiga realizar. A qualquer momento pode desistir de uma tarefa ou até mesmo do próprio teste ou testes.

Cenário: *Você é um Nadador-Salvador de Campo (Regular).*
Use o programa e vigie a praia. Boa Sorte!

Tarefa 1	*[Leia o Código QR da Aplicação]* Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 2	*[Criar uma conta de utilizador e aguarde até ser validada.]* Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 3	*[Faça Login]* Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 4	*[Simule que está a vigiar a praia e aguarde.]* Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 5	*[Recebeu um pedido de ajuda: "Criança Perdida". Clique neste e indique que vai a caminho.]* Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 6	*[Use a aplicação para localizar a Criança perdida no mapa]* Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 7	*[Encontrou a criança! Aceda a aplicação e marque "Situação Resolvida"]* Nada Fácil 1 2 3 4 5 Muito Fácil

Figure .4: Page 1 – Usability Tests for Regular Lifeguards

Tarefa 8	*[Simule que está a vigiar a praia e aguarde]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 9	*[Recebeu um pedido do Supervisor: "Analisar perigo: Detritos no Areal". Clique na localização deste e indique que vai a caminho.]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 10	*[Chegou ao local e há vidros no areal. Confirme a zona de perigo]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 11	*[Simule que está a vigiar a praia e aguarde]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 12	*[O seu mapa indica a localização de um ALERTA "Pré-Afogamento". Aceite o alerta e siga os procedimentos que conhece.]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 13	*[Conseguiu salvar uma vida! Bom trabalho! Marque o alerta como resolvido]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 14	*[Envie uma mensagem a um colega]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 15	*[Na aplicação, troque a bandeira hasteada]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 16	*[Aceda ao seu horário de trabalho]* -- Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 17	*[Peça uma alteração de horário]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Figure .5: Page 2 – Usability Tests for Regular Lifeguards

.2.2 Usability Tests: Beachgoer & Beach Business Owner

Note: Since a Beach Business Owner can also be a Beachgoer, and vice versa, a single usability-test applies to both roles.

Teste com utilizadores

Teste Nº1 - Tablet:

Neste teste nº1 vai ser exposto a um programa (protótipo). Faça as seguintes tarefas por ordem. Em caso de dúvida pode pedir ajuda. As suas ações contribuem para a correção e aperfeiçoamento *do programa e erros existente. ATENÇÃO: Por ser um protótipo, este programa pode ter bugs, pelo que não se sinta frustrado, triste ou zangado por quaisquer tarefas que não consiga realizar. A qualquer momento pode desistir de uma tarefa ou até mesmo do próprio teste ou testes.*
Cenário: *Você é um Banhista e foi à praia do costume com o seu filho. Nesta praia você tem um negócio de praia. Use o programa para conhecer a praia e gerir o seu negócio. Boa Sorte!*

Tarefa 1	*[Leia o Código QR da Aplicação]* ------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 2	*[Criar uma conta de utilizador]* ------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 3	*[Promova a sua conta para negócio]* ------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 4	*[Emparelhe a sua pulseira (Smartband) e a pulseira do seu filho com o seu smartphone.]* ------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 5	*[O seu filho desapareceu! Peça ajuda na aplicação]* ------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 6	*[O seu filho foi encontrado, ufa! Para relaxar vai dar uma volta com ele junto à beira-mar. Na volta você nota muitos vidros no areal. Na aplicação marque a zona como perigosa.]* ------------ Nada Fácil 1 2 3 4 5 Muito Fácil
Tarefa 7	*[Está de volta à sua toalha. Na aplicação verifique as informações gerais da praia]* ------------ Nada Fácil 1 2 3 4 5 Muito Fácil

Figure .6: Page 1 – Usability Tests for Beachgoers and Beach Business Owners

Tarefa 8	*[Na aplicação veja as zonas da costa "perigosas"]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 9	*[Você foi molhar os pés e um idoso tem um corte no pé e necessita de ajuda. Peça ajuda na aplicação.]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 10	*[Está na hora de almoço! Procure bares ou vendedores ambulantes e veja os preços]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 11	*[Está quase na hora de ir trabalhar no seu negócio. Aceda à aplicação e edite o nome do seu negócio]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Tarefa 12	*[Aceda à aplicação e altere o preço de um produto do seu negócio.]* -- Nada Fácil 1 2 3 4 5 Muito Fácil

Figure .7: Page 2 – Usability Tests for Beachgoers and Beach Business Owners