# WRS Evolution

**Version 2.2**

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**CPTS 484_THEIA**

**12/1/25**

# Table of Contents

# Revision History

| Name | Date | Reason for Changes | Version |
|---|---|---|---|
| Justin Keanini | 10/12/25 | Initial draft | 1.0 |
| Julia Lee | 11/01/25 | Revised Section 1-4 | 2.0 |
| Shaya Arya | 11/27/25 | Revised Section 5-9 | 2.1 |
| Andrew Neal | 12/1/25 | Added KAOS goal models | 2.2 |

# 1. Introduction

## 1.1. Purpose of the System

THEIA is an indoor navigation system designed to support individuals with visual impairments in safely and independently navigating university buildings. The system provides voice-guided routing, obstacle detection, contextual environmental descriptions, and emergency assistance features, enabling users to locate destinations without reliance on external help.

## 1.2. Scope of the System

THEIA operates on smartphone devices equipped with a camera, microphone, speaker, and vibration motor, utilizing built-in accessibility functions. The scope of this document includes the following system capabilities:

- Indoor route guidance
- Detection and notification of physical or visual obstacles
- Environmental scanning with real-time verbal description
- Voice-activated emergency assistance
- Accessibility-centered interface, including high-contrast layouts, large text, and haptic feedback

This document addresses Phase 1 tasks involving requirement analysis, problem identification, and improved understanding. Phase 2 will focus on prototyping the core functionalities defined in this specification.

## 1.3. Objectives and Success Criteria

**Objectives**

- Enhance the safety and autonomy of visually impaired users during indoor navigation.
- Detect obstacles and deliver immediate alerts through audio and haptic feedback.
- Enable rapid and minimal-effort emergency requests.
- Provide an accessible user experience that adheres to established accessibility standards.

**Success Criteria**

- Users can initiate navigation using voice commands alone.
- Detected obstacles trigger prompt verbal or haptic warnings.
- Emergency assistance requests are transmitted accurately with location information.
- The interface meets accessibility guidelines for users with low or no vision.

## 1.4. Definitions, Acronyms, and Abbreviations

**THEIA**

Tactile, Haptic, and Environmental Indoor Assistant; the name of the application developed in this project.

**Live View Mode**

A feature that uses the smartphone camera to analyze the environment in real time and provide verbal descriptions.

**ETA (Estimated Time of Arrival)**

The predicted time required for the user to reach the selected destination.

**Accessibility Mode**

A configuration that enables high-contrast visuals, large text, and audio feedback tailored for users with visual impairments.

## 1.5. Overview

Conventional navigation applications often fail to provide accurate indoor positioning and lack obstacle awareness, making them unsuitable for users with visual impairments who require reliable, fine-grained environmental information. THEIA addresses this limitation by integrating indoor mapping, voice-based interaction, real-time obstacle detection, and environmental description.

This document analyzes issues identified in the Preliminary Definition, establishes a refined understanding of the problem domain, and specifies functional and non-functional system requirements. It serves as a foundational reference for subsequent development activities in Phase 2.

# 2. Preliminary Definition

## 2.1. Preliminary Domain

| PD_ID | Preliminary Domain Description |
|---|---|
| PD1 | Individuals with visual impairments who require assistance navigating indoor university environments. |
| PD2 | Indoor spaces that contain potential obstacles such as stairs, turns, furniture, and variable crowd conditions. |

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| PD3 | Situations in which users rely on assistance from others due to insufficient indoor navigation resources. |
| PD4 | General expectations for accessibility features that may involve audio, tactile, or visual elements. |

## 2.2. Preliminary Functional Requirements

| P FR_ ID | Preliminary FR Description |
|---|---|
| PFR1 | The system shall support a form of voice-based interaction for initiating navigation tasks. |
| PFR2 | The system shall include some mechanisms for detecting obstacles in indoor environments. |
| PFR3 | The system shall provide a way for users to request assistance during emergency situations. |
| PFR4 | The system shall include a feature that provides information about the user's surroundings. |
| PFR5 | The system shall offer users general updates related to their progress toward a destination. |
| PFR6 | The system shall allow the user to terminate or modify navigation-related actions. |

## 2.3. Preliminary Non-Functional Requirements

| PNFR_ ID | Preliminary NFR Description |
|---|---|
| PNFR1 | The system shall incorporate general accessibility features suitable for users with varying levels of visual impairment. |
| PNFR2 | The system shall include mechanisms for obtaining user consent when handling personal or location information. |
| PNFR3 | The system shall maintain core functionality under inconsistent or limited network conditions. |

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| PNFR4 | The system interface shall follow basic accessibility design principles to support readability and usability. |
| PNFR5 | The system shall aim to operate efficiently to reduce excessive battery consumption during usage. |

# 3. Issues with the Preliminary Definition Given

## 3.1. Domain Issues

| Domain Issue ID | Domain Issue Description | |
|---|---|---|
| DI1 | PD_ID | PD1. Individuals with visual impairments who require assistance navigating indoor university environments. |
| | 1. The level and type of visual impairment are not distinguished, leading to widely varying needs among users.<br>2. The domain statement does not specify whether the user population includes total blindness, low vision, or mixed impairments, which may require different interaction modes. | |
| | Option 1 | Restrict the target population to one category of visual impairment for clearer requirement scoping. |
| | Option 2 | Prioritize the most common forms of impairment and design requirements around them. |
| | Option 3 | Classify visual impairment into minimal, moderate, and severe categories, and identify which categories the system can realistically support. |
| | Choice | Option 3 |
| | Rationale | This option provides a more detailed understanding of user variability and supports precise mapping between impairments, |

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|---|---|---|
| | | requirements, and features. It also enables clearer traceability between domain problems and system goals. |
| Revised wording | | "THEIA shall support users with moderate to severe visual impairments by providing multimodal navigation assistance within indoor university environments." |

| **Domain Issue ID** | **Domain Issue Description** | |
|---|---|---|
| DI2 | PD_ID | PD2. Indoor spaces that contain potential obstacles such as stairs, turns, furniture, and variable crowd conditions. |
| | 1. The domain description lacks a clear definition of obstacle categories and environmental complexity.<br>2. No distinction is made between static obstacles (walls, furniture) and dynamic obstacles (people, moving objects), which may require different sensing approaches.<br>3. The variability of building layouts is not addressed, risking unrealistic expectations about system coverage. | |
| | Option 1 | Limit obstacles to static features only. |
| | Option 2 | Focus on obstacles that can be detected reliably under typical campus conditions. |
| | Option 3 | Categorize obstacles into static and dynamic types and analyze which category can be supported in Phase 2. |
| | Choice | Option 3 |
| | Rationale | Differentiating obstacle classes allows more accurate functional requirement development and |

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| | | aligns system feasibility with hardware limitations. |
| Revised wording | | "The system shall consider both static and dynamic indoor obstacles and determine which categories can be feasibly detected within Phase 2 constraints." |

| **Domain Issue ID** | **Domain Issue Description** | |
|---|---|---|
| DI3 | PD_ID | PD3. Situations in which users rely on assistance from others due to insufficient indoor navigation resources. |
| | 1. The domain statement does not define the specific conditions under which reliance occurs.<br>2. The privacy and independence concerns are only mentioned implicitly, not explicitly described.<br>3. The nature of user assistance (verbal guidance, physical help, and escorting) remains undefined. | |
| | Option 1 | Narrow the domain to privacy-related scenarios only. |
| | Option 2 | Focus solely on navigation-based assistance contexts. |
| | Option 3 | Identify and categorize forms of assistance and analyze how THEIA can reduce reliance in each case. |
| | Choice | Option 3 |
| | Rationale | This option supports a comprehensive understanding of independence-related challenges and aligns directly with the system's objectives. |
| Revised wording | | "THEIA shall address scenarios in which visually impaired users depend on others for navigation by |

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| | | providing accessible features that promote independence and privacy.” |

| **Domain Issue ID** | **Domain Issue Description** | |
|---|---|---|
| DI4 | PD_ID | PD4. General expectations for accessibility features that may involve audio, tactile, or visual elements. |
| | 1. The domain statement is overly broad and does not specify which accessibility standards or guidelines apply.<br>2. No priorities or conditions for multimodal output (audio versus haptic) are specified.<br>3. The description implies potential features but does not define user scenarios in which each modality is preferable. | |
| | Option 1 | Reduce the domain to a single modality (audio only). |
| | Option 2 | Prioritize audio feedback as the primary mode and treat others as supplementary. |
| | Option 3 | Analyze when each modality is appropriate and identify which combinations the system should support. |
| | Choice | Option 3 |
| | Rationale | Considering multiple output modalities and their contexts supports more accurate requirement identification and better alignment with diverse user needs. |
| Revised wording | | “THEIA shall support multimodal accessibility features and determine contextually appropriate use cases for audio, haptic, and visual feedback.” |

## 3.2. Functional Requirements Issues

| FR Issue ID | Description | |
|---|---|---|
| FRI1 | PFR_ID | PFR1. The system shall support a form of voice-based interaction for initiating navigation tasks. |
| | 1. The preliminary requirement does not specify which voice commands are recognized or how the system interprets ambiguous phrasing.<br>2. It is unclear whether the system supports multiple languages or accents, which affects usability for diverse users.<br>3. The requirement does not define whether alternative input methods are available when voice interaction fails. | |
| | Option 1 | Restrict the system to a set of predefined voice commands for simplicity. |
| | Option 2 | Allow users to customize voice commands based on preference or linguistic needs. |
| | Option 3 | Provide both predefined commands and optional customization, along with fallback input methods. |
| | Choice | Option 3 |
| | Rationale | Offering predefined commands ensures reliability for most users, while optional customization supports inclusivity across accents and languages. A fallback method also improves accessibility in noisy environments. |
| Satisfied by | FR1 | |

| FR Issue ID | Description |
|---|---|

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|---|---|---|
| FRI2 | PFR_ID | PFR2. The system shall include some mechanism for detecting obstacles in indoor environments. |
| | 1. The preliminary requirement does not specify whether the system detects static obstacles, dynamic obstacles, or both.<br>2. Detection accuracy requirements and sensor limitations are not defined.<br>3. It is unclear how the system communicates different types of obstacles to the user. | |
| | Option 1 | Focus solely on static obstacles for Phase 2 feasibility. |
| | Option 2 | Implement dynamic obstacle detection using simple proximity thresholds. |
| | Option 3 | Categorize obstacles and implement differentiated detection and notification strategies. |
| | Choice | Option 3 |
| | Rationale | Comprehensive categorization improves clarity in requirement development and enables scalable implementation in later phases. |
| Satisfied by | FR2 | |

| **FR Issue ID** | **Description** | |
|---|---|---|
| FRI3 | PFR_ID | PFR3. The system shall provide a way for users to request assistance during emergency situations. |
| | 1. The type of emergency scenarios is not defined.<br>2. The requirement does not specify what information is transmitted when requesting help.<br>3. It is unclear whether the system contacts emergency services, personal contacts, or both. | |

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| | Option 1 | Limit emergency assistance to transmitting location to a predefined personal contact. |
| | Option 2 | Allow the user to configure different emergency contact types. |
| | Option 3 | Provide a tiered emergency system including personal contacts, campus security, or predefined services. |
| | Choice | Option 3 |
| | Rationale | A tiered approach allows the system to address a wider range of emergency contexts and enhances user safety. |
| Satisfied by | FR3 | |

| **FR Issue ID** | **Description** | |
|---|---|---|
| FRI4 | PFR_ID | PFR4. The system shall include a feature that provides information about the user's surroundings. |
| | 1. The preliminary requirement does not specify what environmental elements should be described.<br>2. It is unclear how detailed the descriptions need to be.<br>3. The requirement does not address latency or frequency of environmental updates. | |
| | Option 1 | Provide only basic orientation cues such as nearby walls or open space. |
| | Option 2 | Provide detailed environmental descriptions when requested. |
| | Option 3 | Provide layered descriptions that adjust dynamically based on user preference and context. |

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| | Choice | Option 3 |
| | Rationale | Layered descriptions allow the system to serve different impairment levels and reduce information overload. |
| Satisfied by | FR4 | |

| **FR Issue ID** | **Description** | |
|---|---|---|
| FRI5 | PFR_ID | PFR5. The system shall offer users general updates related to their progress toward a destination. |
| | 1. The requirement does not specify how frequently updates are provided.<br>2. ETA accuracy expectations are not defined.<br>3. It is unclear whether distance updates are continuous or user initiated. | |
| | Option 1 | Provide updates only when explicitly requested by the user. |
| | Option 2 | Provide updates at fixed intervals. |
| | Option 3 | Provide context adaptive updates that balance information load and accuracy. |
| | Choice | Option 3 |
| | Rationale | Adaptive updates improve usability and comfort by reducing unnecessary interruptions while maintaining helpful guidance. |
| Satisfied by | FR5 | |

| **FR Issue ID** | **Description** | |
|---|---|---|
| FRI6 | PFR_ID | PFR6. The system shall allow the user to terminate or modify navigation related actions. |

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| | 1. The requirement does not specify available interaction modes for cancellation.<br>2. User safety considerations during abrupt route termination are not described.<br>3. It is unclear whether the system confirms termination to prevent accidental cancellation. | |
| | Option 1 | Allow cancellation through voice commands only. |
| | Option 2 | Allow cancellation through both touch and voice. |
| | Option 3 | Provide multiple cancellation modes with confirmation prompts for safety. |
| | Choice | Option 3 |
| | Rationale | Multiple cancellation modes improve accessibility, while confirmation prompts prevent unintended navigation interruptions. |
| Satisfied by | FR6 | |

## 3.3. Non-Functional Requirements (NFR) Issues

| **NFR Issues ID** | **Description** | |
|---|---|---|
| NFRI1 | PNFR_ID | PNFR1. The system shall incorporate general accessibility features suitable for users with varying levels of visual impairment. |
| | The requirement is overly broad and does not specify which accessibility guidelines or modalities apply. The definition of accessibility in this context remains unclear. | |

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|---|---|---|
| | Option1 | Interpret accessibility primarily as compliance with established standards such as WCAG. |
| | Option2 | Interpret accessibility as multimodal support through audio, haptic, and visual feedback. |
| | Option3 | Interpret accessibility as the ability to adjust interface elements to user preferences. |
| | Choice | Option 2 |
| | Rationale | Multimodal feedback aligns directly with the needs of visually impaired users and supports practical functional requirements for THEIA. |
| Satisfied by | NFRI1 | |

| **NFR Issues ID** | **Description** | |
|---|---|---|
| NFRI2 | PNFR_ID | PNFR2. The system shall include mechanisms for obtaining user consent when handling personal or location information. |
| | The preliminary statement does not clarify what constitutes meaningful consent or how it should be obtained. | |
| | Option1 | Define consent as a one time agreement during initial setup. |
| | Option2 | Require consent each time sensitive information is transmitted. |

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| | Option3 | Provide tiered consent options that allow users to select the level of data sharing they accept. |
| | Choice | Option 3 |
| | Rationale | Tiered consent better reflects modern privacy expectations and improves transparency for visually impaired users. |
| Satisfied by | NFR2 | |

| **NFR Issues ID** | **Description** | |
|---|---|---|
| NFRI3 | PNFR_ID | PNFR3. The system shall maintain core functionality under inconsistent or limited network conditions. |
| | The requirement does not specify which features must remain available offline or with reduced connectivity. | |
| | Option1 | Requires the entire system to function without network access. |
| | Option2 | Maintain only essential navigation features offline. |
| | Option3 | Categorize features into online and offline groups according to feasibility. |
| | Choice | Option 3 |
| | Rationale | Grouping features by connectivity needs supports realistic design constraints and clarifies system expectations. |
| Satisfied by | NFR3 | |

| NFR Issues ID | Description | |
|---|---|---|
| NFRI4 | PNFR_ID | PNFR4. The system interface shall follow basic accessibility design principles to support readability and usability. |
| | The preliminary requirement does not define specific design metrics such as font size, contrast ratios, or layout constraints. | |
| | Option1 | Follow only WCAG minimal guidelines. |
| | Option2 | Allow users to customize interface parameters. |
| | Option3 | Combine WCAG compliance with user adjustable accessibility controls. |
| | Choice | Option 3 |
| | Rationale | A hybrid approach ensures universal access while accommodating individual needs across the visually impaired population. |
| Satisfied by | NFR4 | |

| NFR Issues ID | Description | |
|---|---|---|
| NFRI5 | PNFR_ID | PNFR5. The system shall aim to operate efficiently to reduce excessive battery consumption during usage. |
| | The preliminary requirement does not specify acceptable battery usage or conditions that influence power consumption. | |
| | Option1 | Limit high power functions such as Live View Mode. |

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| | Option2 | Dynamically adjust sensor usage based on user movement. |
| | Option3 | Implement adaptive power management strategies that respond to context and task demands. |
| | Choice | Option 3 |
| | Rationale | Adaptive management improves battery life without sacrificing core functionality, especially during extended navigation sessions. |
| Satisfied by | NFR5 | |

# 4. WRS

## 4.1. W

### 4.1.1. Problem

| Problem ID | Problem Description | Corresponding Goals |
|---|---|---|
| P1 | Users with visual impairments experience varying levels of difficulty when navigating indoor university environments due to differences in impairment severity and lack of tailored support. | G1: Provide adaptable navigation assistance that accommodates moderate to severe visual impairments. |
| P2 | Indoor environments contain diverse static and dynamic obstacles, yet the system lacks a clear strategy for detecting, distinguishing, and communicating these hazards effectively. | G2: Deliver reliable obstacle detection with differentiated alerts based on obstacle type and urgency. |
| P3 | Users often rely on external assistance for navigation, which reduces independence and raises privacy | G3: Reduce dependence on others by enabling |

| | | |
|---|---|---|
| | concerns, especially in unfamiliar or crowded buildings. | users to navigate autonomously with accurate and accessible indoor guidance. |
| P4 | Accessibility requirements for multimodal feedback are insufficiently defined, leading to uncertainty about when to use audio, haptic, or visual outputs for optimal user experience. | G4: Provide context sensitive multimodal feedback that adjusts to user preference, environment, and accessibility needs. |

### 4.1.2. Goals

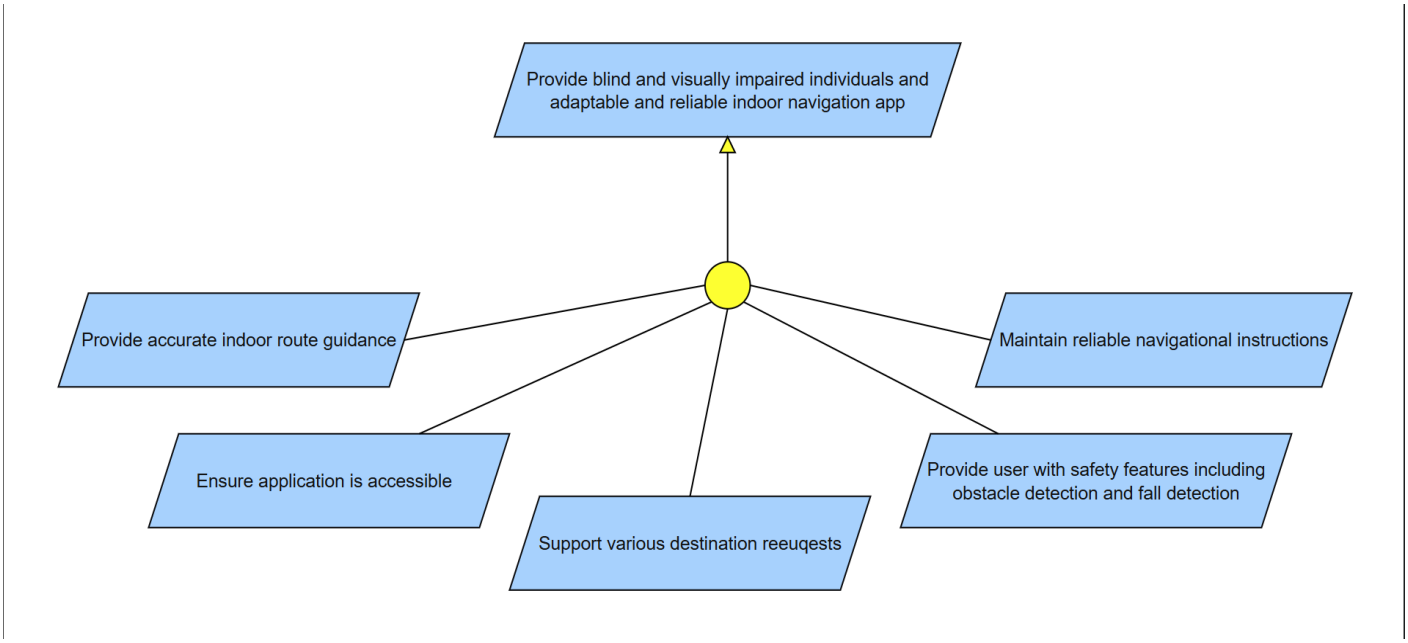



Figure 1. Goal: “Provide blind and visually impaired individuals with a reliable indoor navigation app”

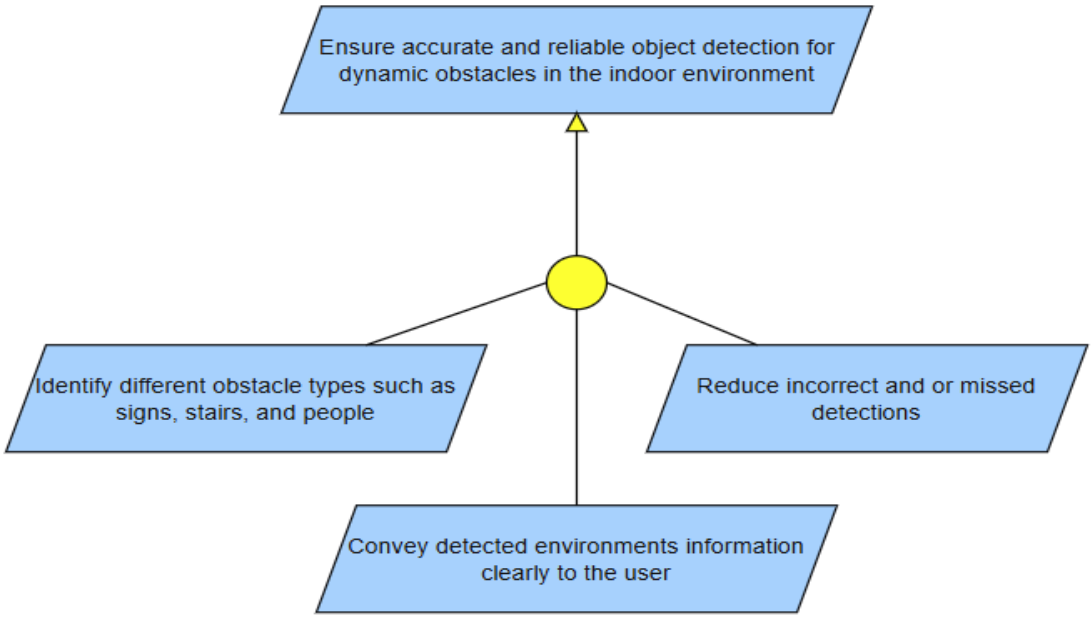



Figure 2. Goal: “Provide users with reliable and accurate object detection for improved user safety”

| Goal ID | Goal Description | Backward Traceability | Forward Traceability |
|---|---|---|---|
| G1 | Provide adaptable navigation assistance that accommodates varying levels of visual impairment. | P1 | FO1 |
| G2 | Ensure accurate detection and communication of both static and dynamic indoor obstacles. | P2 | FO2 |
| G3 | Enable users to navigate independently without relying on external assistance. | P3 | FO3 |
| G4 | Deliver multimodal feedback (audio, haptic, visual) that dynamically adapts to user preferences and environmental conditions. | P4 | FO4 |
| G5 | Support real-time environmental awareness through descriptive spatial information. | P2 | FO5 |

### 4.1.3. Improved Understanding of Domain, Stakeholders, Functional, and Non-Functional Objectives

#### 4.1.3.1. Improved Domain: Disabilities

| Improved Domain ID | Improved Domain Description |
|---|---|
| D1 | THEIA shall support users with moderate to severe visual impairments, including reduced acuity, limited contrast sensitivity, light sensitivity, and restricted field of view. |
| D2 | THEIA shall accommodate users who experience difficulty in detecting spatial cues, interpreting indoor layouts, or recognizing environmental hazards due to visual limitations. |
| D3 | THEIA shall reduce dependence on external assistance by enabling visually impaired users to independently navigate unfamiliar indoor environments. |

| | |
|---|---|
| D4 | THEIA shall provide accessibility centered interaction methods tailored to the capabilities of visually impaired individuals, including voice input, haptic alerts, and high contrast visuals. |

## 4.1.3.2. Improved Domain: Activities

| Improved Domain ID | Improved Domain Description |
|---|---|
| A1 | THEIA shall support indoor navigation between key campus locations such as classrooms, offices, restrooms, elevators, and common areas. |
| A2 | THEIA shall assist users in avoiding environmental obstacles, including static structures such as walls and doors and dynamic elements such as moving individuals. |
| A3 | THEIA shall provide situational awareness activities such as describing surroundings, identifying points of interest, and clarifying orientation cues. |
| A4 | THEIA shall enable emergency response activities, including quick activation of alerts and transmission of the user's location to designated contacts. |
| A5 | THEIA shall support users in monitoring navigational progress through distance updates, direction cues, and estimated time of arrival. |

## 4.1.3.3. Stakeholders

**Sponsors**

- Research: Department of Computer Science, Washington State University
- Faculty: Bolong Zeng - Responsible for evaluation and project oversight

**Potential Users of THEIA**

- Individuals with moderate to severe visual impairments who require indoor navigation assistance in university buildings
- Visually Impaired Students
- Utilize navigation guidance, obstacle detection, environmental descriptions, and emergency assistance features to move independently within campus facilities
- Disability Access Staff

- Monitor and evaluate accessibility needs across campus environments and may use THEIA to validate indoor mobility challenges
- Campus Safety and Security Personnel
- Receive emergency notifications or location data when users request assistance
- Caretakers or Support Providers
- Configure user preferences, emergency contact details, and accessibility settings for primary users who require setup support

## 4.1.3.4. Improved Functional Objectives

Based on the above information and our goals, the functional objectives of THEIA are:

| **Improved FR Objective ID** | **Objective Description** | **Alleviates Problems** | **Achieves Goals** |
|---|---|---|---|
| IFRO1 | THEIA shall provide adaptive voice-based navigation functions that guide visually impaired users between indoor points of interest. | P1 | G1, G3 |
| IFRO2 | THEIA shall detect static and dynamic obstacles and communicate their presence using context appropriate alerts. | P2 | G2 |
| IFRO3 | THEIA shall support emergency assistance requests by transmitting relevant information such as user identity and location to designated contacts or campus services. | P3 | G3 |
| IFRO4 | THEIA shall offer multimodal environmental descriptions through camera analysis to improve situational awareness during navigation. | P2, P4 | G4, G5 |
| IFRO5 | THEIA shall provide progress-related feedback including remaining distance, direction updates, and estimated time of arrival based on user request or system context. | P1, P3 | G1, G3 |

## 4.1.3.5. Improved Non-Functional Objectives

| Improved NFR Objective ID | Objective Description | Alleviates Problem | Achieves Goal |
|---|---|---|---|
| INFRO1 | THEIA shall ensure that accessibility features, including audio, haptic, and visual feedback, remain usable across varying visual impairment levels. | P1 | G1 |
| INFRO2 | THEIA shall provide tiered privacy and consent controls to protect user information, including location data shared during navigation or emergencies. | P3 | G3 |
| INFRO3 | THEIA shall maintain essential navigation and alerting functions under inconsistent or limited network connectivity. | P2 | G2 |
| INFRO4 | THEIA shall comply with accessibility design principles by maintaining readable layouts, large fonts, and high contrast to support users with low vision. | P4 | G4 |
| INFRO5 | THEIA shall optimize power consumption through adaptive resource management to support extended navigation sessions. | P2 | G5 |

## 4.2. RS

### 4.2.1. Functional Requirements

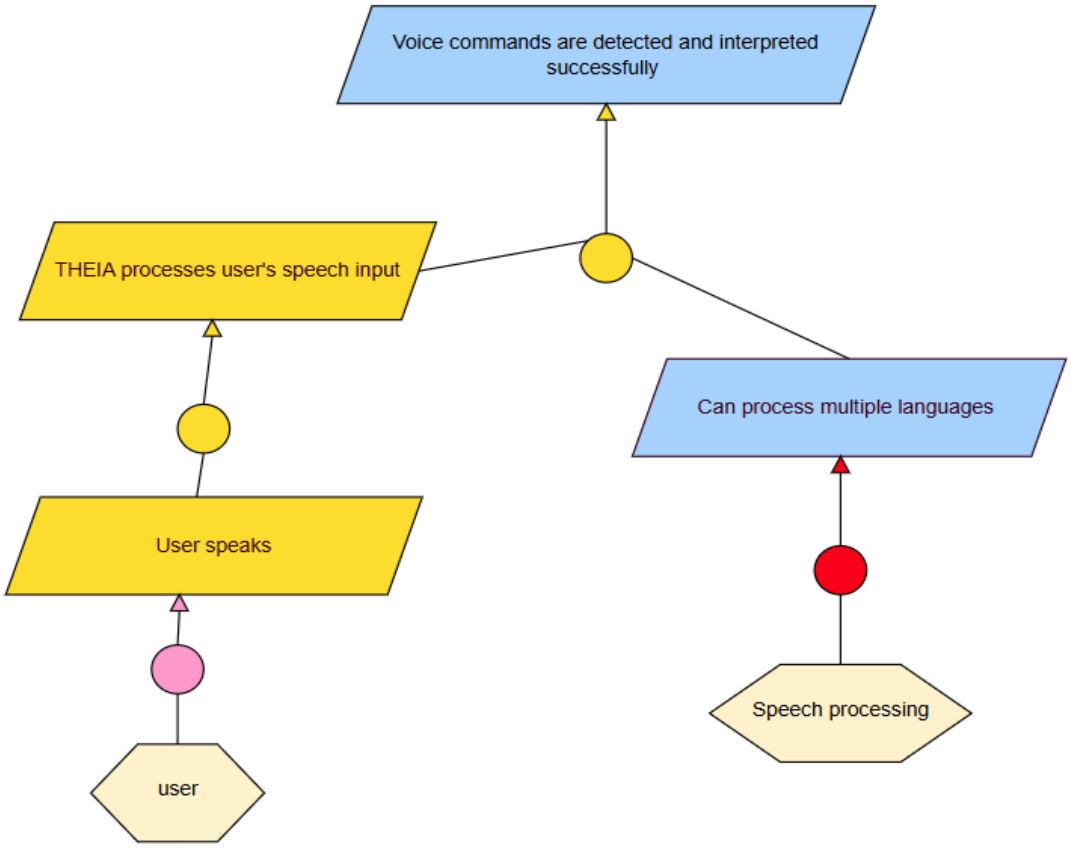



Figure 3. Responsibility: “interpret voice user command successfully”

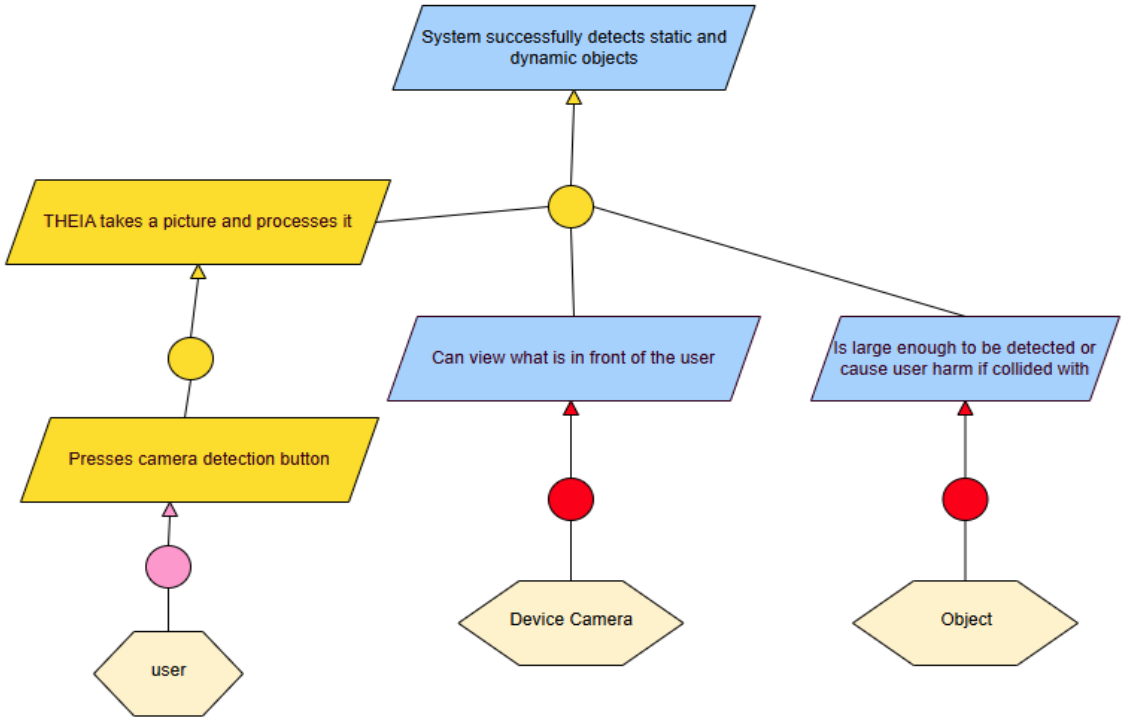



Figure 4. Responsibility: “Detect both static and dynamic obstacles withing users' path”

| **FR ID** | **Description** |
|---|---|
| FR1 | When a user initiates a voice command, the system shall interpret the spoken input. |
| Satisfies Functional Requirement Issue | FRI1 |
| Satisfies Objectives | IFRO1, IFRO5 |
| Satisfied by prototype feature | Voice activated navigation trigger |

| **FR ID** | **Description** |
|---|---|
| FR2 | The system shall detect both static and dynamic obstacles within the user’s path and provide |

| | |
|---|---|
| | context appropriate alerts through audio feedback. |
| Satisfies Functional Requirement Issue | FRI2 |
| Satisfies Objectives | IFRO2 |
| Satisfied by prototype feature | Obstacle detection module with alert output |

| **FR ID** | **Description** |
|---|---|
| FR3 | The system shall allow users to request emergency assistance through a single voice command or gesture and transmit the user's location and identity to predefined contacts or campus services. |
| Satisfies Functional Requirement Issue | FRI3 |
| Satisfies Objectives | IFRO3 |
| Satisfied by prototype feature | Emergency help request and notification |

| **FR ID** | **Description** |
|---|---|
| FR4 | The system shall provide real time environmental descriptions using camera based analysis, delivering spatial information such as nearby structures or pathways. |
| Satisfies Functional Requirement Issue | FRI4 |
| Satisfies Objectives | IFRO4 |

| | |
|---|---|
| Satisfied by prototype feature | Live View Mode environment description |

| **FR ID** | **Description** |
|---|---|
| FR5 | The system shall provide progress updates, including remaining distance, directional guidance, and estimated time of arrival, either upon request or when contextually appropriate. |
| Satisfies Functional Requirement Issue | FRI5 |
| Satisfies Objectives | IFRO1, IFRO5 |
| Satisfied by prototype feature | Navigation progress indicator |

| **FR ID** | **Description** |
|---|---|
| FR6 | The system shall allow users to cancel or modify navigation actions through voice commands or touch interactions, with confirmation prompts to prevent unintended termination. |
| Satisfies Functional Requirement Issue | FRI6 |
| Satisfies Objectives | IFRO1 |
| Satisfied by prototype feature | Navigation cancel or modify control |

## 4.2.2. Non-Functional Requirements

| **NFR ID** | **Nonfunctional Requirement 1** | |
|---|---|---|
| NFR1 | The system shall ensure data confidentiality by protecting user identity, location information, and emergency contact details from unauthorized access. | |
| Operationalized Functional Requirements | OFR1<br><br>OFR2 | The system shall require user consent before accessing or transmitting personal or location data. |

| | | |
|---|---|---|
| | | The system shall provide a secure consent management interface that allows users or caretakers to configure data sharing preferences. |
| Satisfies Nonfunctional Requirement Issue | NFRI1 | |
| Satisfies Non-functional Objective | INFRO2 | |
| Constrains | IFRO3, IFRO4 | |
| Satisfied by prototype feature | Privacy and consent configuration module | |

| **NFR ID** | **Nonfunctional Requirement 1** | |
|---|---|---|
| NFR2 | The system shall tolerate intermittent connectivity by queuing requests and providing graceful degradation. Offline operation is not required for the initial release. | |
| Operationalized Functional Requirements | OFR3<br><br>OFR4 | The system shall provide caching where available to indoor maps required for basic navigation.<br><br>The system shall maintain reduced functionality with connectivity loss for obstacle detection and environmental descriptions when network connectivity is unavailable. |
| Satisfies Nonfunctional Requirement Issue | NFRI3 | |
| Satisfies Non-functional Objective | INFRO3 | |
| Constrains | IFRO2, IFRO4 | |
| Satisfied by prototype feature | Queued requests, local caching of floorplans, and reduced functionality under connectivity loss. | |

| **NFR ID** | **Nonfunctional Requirement 1** | |
|---|---|---|
| NFR3 | The system interface shall adhere to accessibility design principles by maintaining readable layouts, large font sizes, and high contrast for visually impaired users. | |
| Operationalized Functional Requirements | OFR5<br><br>OFR6 | The system shall allow users or caretakers to configure font size, contrast mode, and layout scaling.<br><br>The system shall support automatic high contrast mode activation when ambient lighting is low. |
| Satisfies Nonfunctional Requirement Issue | NFRI4 | |
| Satisfies Non-functional Objective | INFRO4 | |
| Constrains | IFRO1, IFRO4 | |
| Satisfied by prototype feature | Adjustable accessibility interface | |

| **NFR ID** | **Nonfunctional Requirement 1** | |
|---|---|---|
| NFR4 | The system shall minimize power consumption during navigation sessions through adaptive resource management. | |
| Operationalized Functional Requirements | OFR7<br><br>OFR8 | The system shall reduce camera usage when the user is moving continuously in a predictable direction.<br><br>The system shall adjust sensor polling frequency based on user motion and environmental stability. |
| Satisfies Nonfunctional Requirement Issue | NFRI5 | |

| | |
|---|---|
| Satisfies Non-functional Objective | INFRO5 |
| Constrains | IFRO1, IFRO2, IFRO4 |
| Satisfied by prototype feature | Power optimized sensor and camera control |

### 4.2.3. Specifications

| **Functional Specification ID** | **Functional Requirement** |
|---|---|
| FS1 | When a user issues a valid voice command, the system shall interpret the spoken input and activate the appropriate navigation or system function. |
| Satisfies Functional Requirement | FR1 |
| Satisfies Objectives | IFRO1, IFRO5 |
| Satisfied by prototype feature | Voice command processing module |

| **Functional Specification ID** | **Functional Requirement** |
|---|---|
| FS2 | The system shall scan the surrounding indoor environment using device sensors and identify static or dynamic obstacles within a defined detection radius. |
| Satisfies Functional Requirement | FR2 |
| Satisfies Objectives | IFRO2 |
| Satisfied by prototype feature | Obstacle detection sensor module |

| **Functional Specification ID** | **Functional Requirement** |
|---|---|
| FS3 | When an emergency command is detected, the system shall automatically transmit the user's identity and location to designated contacts or campus services. |
| Satisfies Functional Requirement | FR3 |
| Satisfies Objectives | IFRO3 |

| | |
|---|---|
| Satisfied by prototype feature | Emergency assistance transmitter |

| Functional Specification ID | Functional Requirement |
|---|---|
| FS4 | The system shall analyze live camera input to generate environmental descriptions, including spatial layout and nearby structures. |
| Satisfies Functional Requirement | FR4 |
| Satisfies Objectives | IFRO4 |
| Satisfied by prototype feature | Live View Mode environment analysis |

# 5. Preliminary Prototype

Below is an overview of the preliminary prototype for the THEIA application. The prototype is organized by major functional components.

**Voice Activated Navigation Module**

This component demonstrates the system's ability to recognize predefined voice commands and initiate navigation tasks. The prototype includes a minimal interface for voice input processing and command mapping.

**Contents:**

- Functional description
- Sample command recognition workflow
- Mock command mapping table
- Basic testing conditions for accuracy and response time

**Obstacle Detection and Alerting Module**

This component shows preliminary capabilities for detecting nearby obstacles using device sensors. Static detection logic and simple proximity thresholds are included in the prototype.

**Contents:**

- Functional overview
- Sample sensor polling routines
- Detection radius configuration
- Testing metrics for alert timing and reliability

**Emergency Assistance Module**

This module demonstrates how an emergency trigger leads to the transmission of user information to a designated contact. The prototype focuses on command recognition and data packaging.

**Contents:**

- Emergency command detection
- Prototype data transmission logic
- Mock contact registry
- Testing scenarios for activation consistency

**Live View Environmental Description Module**

This component provides a basic implementation of camera-based environmental scanning. The preliminary version includes object recognition placeholders and descriptive text generation prototypes.

**Contents:**

- Camera input processing outline
- Sample environmental description outputs
- Performance notes on latency
- Prototype test cases

**Navigation Progress and ETA Module**

This module presents a simplified model for tracking user movement during navigation. The prototype includes distance estimation, direction updates, and time prediction of placeholders.

**Contents:**

- Functional description
- Example ETA calculation flow
- Mock data for navigation updates
- Testing considerations for timing and accuracy

# 6. Prototype Interface Mock-ups

The following interface mock-ups illustrate the primary screens, and interaction flows of the THEIA application. Each mock-up is designed to comply with accessibility standards and support multimodal interaction patterns for visually impaired users.

## 6.1. Home Screen

The home screen serves as the primary navigation hub for THEIA. It features a high-contrast layout with large, clearly labeled buttons arranged for easy touch access.

**Screen Elements:**

- Navigation Button: Large rectangular button labeled "Start Navigation" that occupies 25% of screen, activates voice command listening mode when pressed
- Live View Button: Opens camera-based environmental scanning mode with verbal descriptions
- Emergency Button: Red-colored button at bottom of screen for quick access to emergency assistance
- Settings Icon: Located in top-right corner for accessing accessibility preferences

**Accessibility Features:**

- Minimum touch target size of 48x48 dp for all interactive elements
- Text labels with minimum 18sp font size and contrast ratio of 7:1
- Full screen reader compatibility with descriptive content labels
- Haptic feedback on button press confirmation


Home Screen

## 6.2. Destination Selection Screen

This screen allows users to select their destination through voice input or touch-based list selection.

**Screen Elements:**

- Voice Input Button: Microphone icon that activates speech recognition for destination entry
- Recent Destinations List: Scrollable list of recently visited locations

• Categories List: Building categories including Classrooms, Offices, Restrooms, Elevators, Exits

• Search Field: Text input for manual destination search with auto-complete suggestions


Destination Selection

## 6.3. Navigation Screen

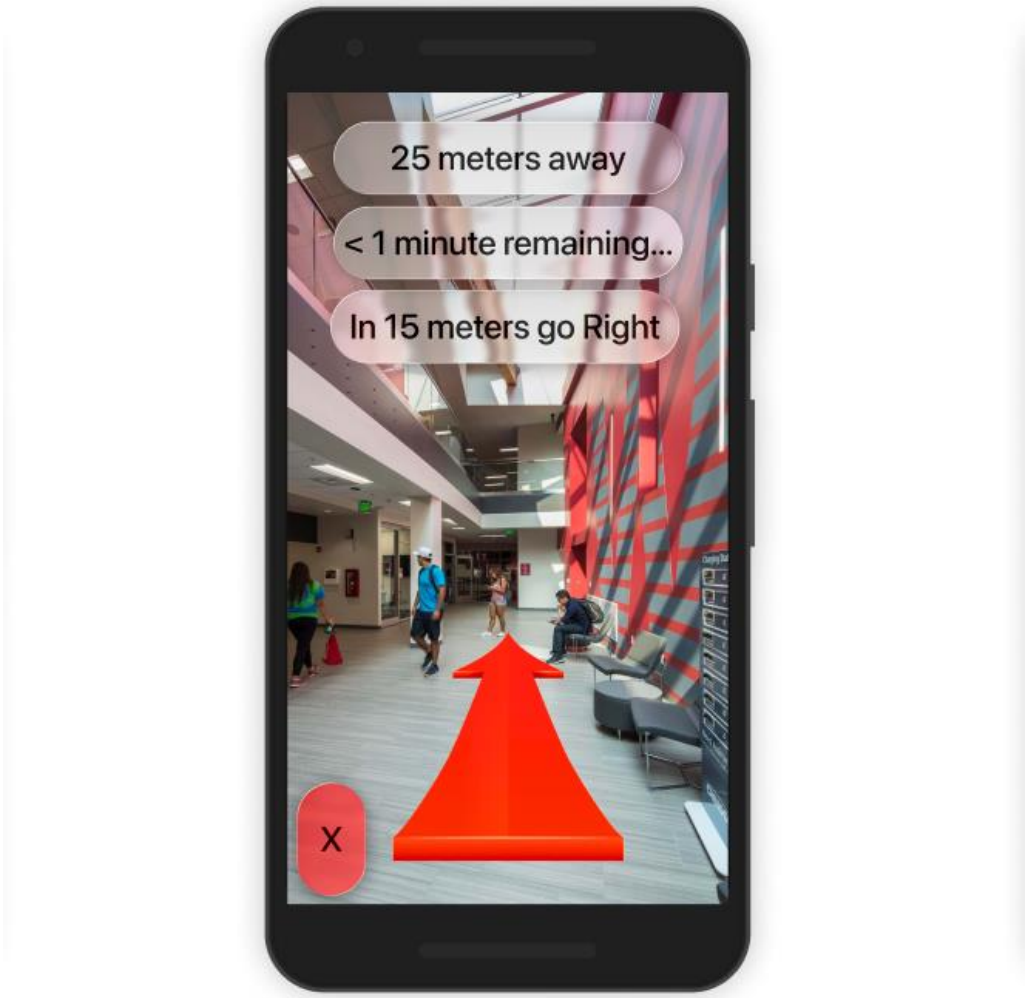
The navigation screen provides real-time guidance during active navigation sessions. The interface prioritizes voice-based interaction while maintaining visual indicators for users with partial vision.

**Screen Elements:**

- Direction Indicator: Large arrow graphic showing current heading direction, updates dynamically
- Distance Display: Numeric display showing remaining distance to destination in feet or meters
- ETA Display: Estimated time of arrival in minutes
- Next Instruction Banner: Text display showing the next navigation instruction
- Cancel Button: Allows user to terminate current navigation with confirmation prompt

**Voice Interaction:**

- Automatic voice announcements for direction changes and obstacles
- Voice commands supported: "repeat", "how far", "cancel", "help"
- Configurable verbosity levels for navigation instructions




Navigation

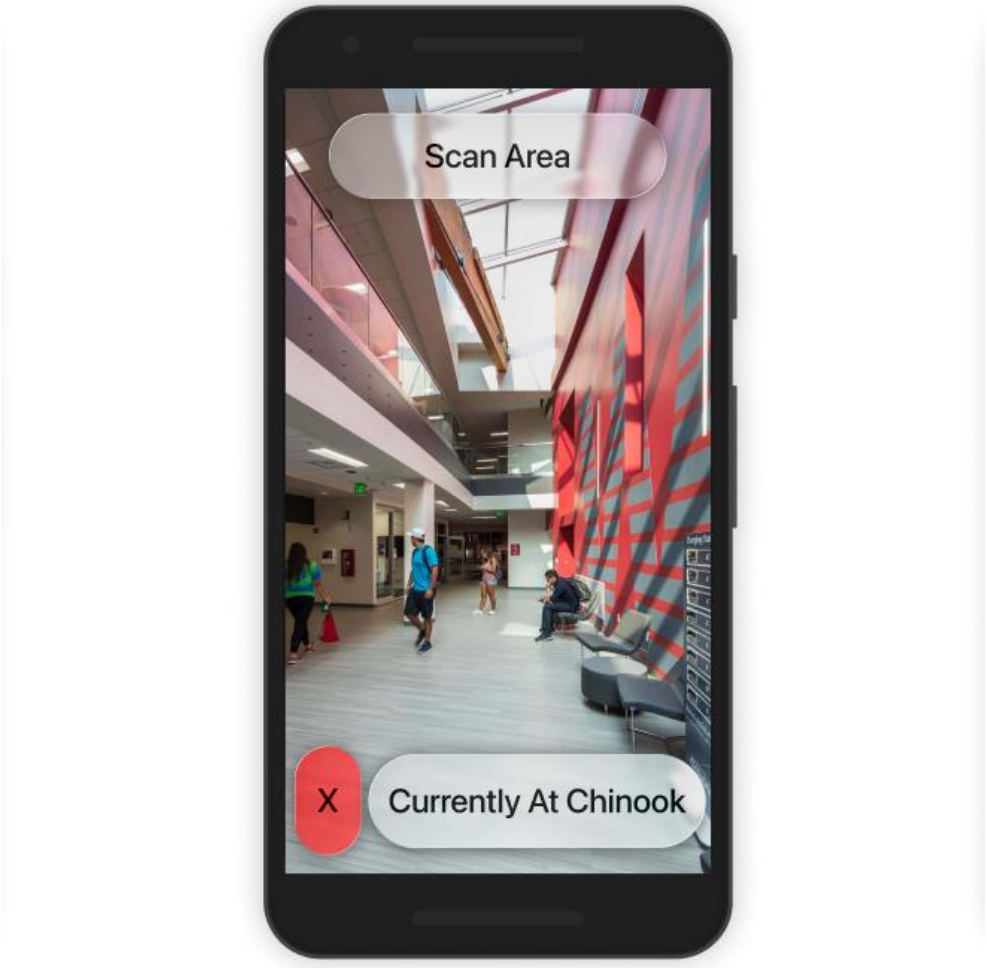
## 6.4. Live View Mode Screen

The Live View screen displays camera feed with real-time environmental analysis and verbal descriptions of the surroundings.

**Screen Elements:**

- Camera Preview: Full-screen camera view with overlay indicators for detected objects
- Description Panel: Bottom overlay showing text of current environmental description
- Scan Button: Triggers detailed scan and verbal description of current view

• Close Button: Returns to home screen




Live View Mode

## 6.5. Emergency Assistance Screen

This screen provides rapid access to emergency assistance with minimal interaction required.

**Screen Elements:**

• Emergency Call Button: Large red button to contact campus security immediately

• Personal Contact Button: Sends location and alert to pre-configured personal contacts

• Location Display: Shows current indoor location for user reference

• Cancel Button: Returns to previous screen if activated accidentally


Emergency Assistance

## 6.6. Settings Screen

The settings screen allows users and caretakers to configure accessibility preferences and application behavior.

**Configurable Options:**

• Font Size: Adjustable from 14sp to 32sp with preview

• Contrast Mode: Normal, High Contrast, and Inverted color schemes

- Voice Speed: Speech rate adjustment from 0.5x to 2.0x
- Emergency Contacts: Management of personal emergency contact list
- Privacy Settings: Data sharing and consent configuration


Settings

# 7. User Manual

This user manual provides comprehensive instructions for operating the THEIA indoor navigation system. The manual is organized by primary functions and includes step-by-step procedures for all major features.

## 7.1. Getting Started

### 7.1.1. Initial Setup

1. Download THEIA from your device's application store
2. Open the application and grant required permissions: Camera, Microphone, Location
3. Complete the accessibility preference survey to configure initial settings
4. Add emergency contacts when prompted
5. Download campus floorplans for caching for your campus buildings

### 7.1.2. Understanding the Interface

The THEIA interface uses large buttons with high contrast and full screen reader support. All buttons provide audio feedback when selected. The home screen contains four main options: Start Navigation, Live View, Emergency, and Settings.

## 7.2. Navigation Features

### 7.2.1. Starting Navigation

To begin navigation to a destination:

1. Press the "Start Navigation" button on the home screen or say "Navigate"
2. Speak your destination clearly (e.g., "Room 302" or "North elevator")
3. Confirm the destination when THEIA repeats it back to you
4. Follow the voice instructions to reach your destination

### 7.2.2. Voice Commands During Navigation

• "Repeat" - Repeats the last navigation instruction

• "How far" - Announces remaining distance and estimated time

• "Where am I" - Describes current location

• "Pause" - Pauses navigation instructions temporarily

• "Resume" - Resumes paused navigation

• "Cancel" - Terminates current navigation with confirmation

### 7.2.3. Understanding Navigation Instructions

THEIA provides instructions using clock positions for turning directions (e.g., "Turn to 3 o'clock") and step counts for distances. Instructions are adjusted based on your verbosity preference setting. Obstacle warnings include the type of obstacle and recommended action.

## 7.3. Obstacle Detection

THEIA continuously monitors your path for obstacles and provides alerts through audio and haptic feedback.

### 7.3.1. Alert Types

- Proximity Alert: Single vibration and tone for obstacles within 3 meters
- Immediate Alert: Double vibration and urgent tone for obstacles within 1 meter
- Dynamic Obstacle Alert: Distinct pattern for moving obstacles such as people

## 7.4. Live View Mode

Live View Mode provides real-time verbal descriptions of your environment using the device camera.

### 7.4.1. Using Live View

1. Press the "Live View" button or say "Describe surroundings"
2. Point the camera in the direction you want to analyze
3. Press "Scan" or say "Scan" to receive a description
4. Say "More detail" for extended descriptions of specific objects

## 7.5. Emergency Assistance

### 7.5.1. Requesting Help

1. Press the red Emergency button on any screen, or say "Emergency"
2. Select "Campus Security" for immediate security response
3. Select "Contact" to alert your personal emergency contacts
4. Your location is automatically transmitted with the alert

### 7.5.2. Canceling Accidental Activation

If you activate the emergency screen accidentally, press "Cancel" within 5 seconds before the alert is sent. A countdown timer provides audio feedback during this window.

## 7.6. Adjusting Settings

### 7.6.1. Accessibility Settings

Access settings by pressing the gear icon in the top-right corner of the home screen or saying "Settings":

- Text Size: Use slider to adjust font size from 14sp to 32sp
- Contrast: Select Normal, High Contrast, or Inverted themes
- Voice Speed: Adjust speech rate from 0.5x to 2.0x
- Vibration Intensity: Set haptic feedback strength

### 7.6.2. Privacy and Consent

Configure data sharing preferences in Settings > Privacy. You can enable or disable location sharing for navigation, analytics data collection, and emergency contact notification. All privacy settings require explicit consent and can be changed at any time.

## 7.7. Troubleshooting

### 7.7.1. Common Issues

- Voice commands not recognized: Speak clearly, reduce background noise, check microphone permissions
- Navigation unavailable: Ensure you are in a mapped building and have downloaded offline maps
- No obstacle alerts: Check that camera permissions are enabled and lens is not obstructed

• High battery usage: Reduce Live View usage and enable adaptive power management in settings

# 8. Traceability

This section presents comprehensive traceability matrices that link problems, goals, objectives, and requirements throughout the THEIA system specification. These matrices ensure complete coverage and bidirectional traceability between all specification elements.

## 8.1. Problem-to-Goal Traceability

The following matrix traces each identified problem to its corresponding goals, demonstrating that all problems are addressed by system objectives.

| Problem ID | Problem Summary | Goals Addressed |
|---|---|---|
| P1 | Varying difficulty navigating due to impairment differences | G1 |
| P2 | Diverse obstacles without clear detection strategy | G2, G5 |
| P3 | Dependence on external assistance reduces independence | G3 |
| P4 | Insufficiently defined multimodal accessibility requirements | G4 |

## 8.2. Goal-to-Functional Objective Traceability

This matrix maps goals to the functional objectives that achieve them, ensuring all goals have corresponding implementation targets.

| Goal ID | Goal Summary | Functional Objectives |
|---|---|---|
| G1 | Adaptable navigation for varying impairment levels | IFRO1, IFRO5 |

| | | |
|---|---|---|
| G2 | Accurate obstacle detection and communication | IFRO2 |
| G3 | Independent navigation without external assistance | IFRO1, IFRO3, IFRO5 |
| G4 | Dynamic multimodal feedback adaptation | IFRO4 |
| G5 | Real-time environmental awareness | IFRO4, IFRO5 |

## 8.3. Functional Objective-to-Requirement Traceability

This matrix links functional objectives to the specific requirements that implement them.

| Objective ID | Objective Summary | Requirements |
|---|---|---|
| IFRO1 | Adaptive voice-based navigation functions | FR1, FR5, FR6 |
| IFRO2 | Obstacle detection with context-appropriate alerts | FR2 |
| IFRO3 | Emergency assistance with location transmission | FR3 |
| IFRO4 | Multimodal environmental descriptions via camera | FR4 |
| IFRO5 | Progress feedback with distance, direction, ETA | FR5 |

## 8.4. Non-Functional Objective-to-Requirement Traceability

This matrix maps non-functional objectives to their implementation requirements.

| Objective ID | Objective Summary | Requirements |
|---|---|---|
| INFRO1 | Accessibility across varying impairment levels | NFR3 |
| INFRO2 | Tiered privacy and consent controls | NFR1 |
| INFRO3 | Essential functions under limited connectivity | NFR2 |
| INFRO4 | Accessible design with readable layouts | NFR3 |
| INFRO5 | Optimized power consumption | NFR4 |

## 8.5. Requirement-to-Prototype Feature Traceability

This matrix traces each functional requirement to its corresponding prototype feature, ensuring all requirements have demonstrable implementations.

| FR ID | Requirement Summary | Prototype Feature |
|---|---|---|
| FR1 | Voice command interpretation | Voice Activated Navigation Module |
| FR2 | Obstacle detection and alerting | Obstacle Detection and Alerting Module |
| FR3 | Emergency assistance requests | Emergency Assistance Module |
| FR4 | Environmental descriptions via camera | Live View Environmental Description Module |
| FR5 | Progress updates and ETA | Navigation Progress and ETA Module |
| FR6 | Navigation cancellation with confirmation | Voice Activated Navigation Module |

### 8.6. Complete Traceability Summary

The traceability analysis confirms complete coverage: all four identified problems are addressed by corresponding goals, all goals have functional objectives that achieve them, and all functional and non-functional requirements trace back to specific objectives. The prototype implements demonstrable features for each functional requirement.

# 9. References

## 9.1. Accessibility Standards

[1] World Wide Web Consortium. (2018). Web Content Accessibility Guidelines (WCAG) 2.1. W3C Recommendation. https://www.w3.org/TR/WCAG21/

[2] Apple Inc. (2024). Human Interface Guidelines: Accessibility. Apple Developer Documentation. https://developer.apple.com/design/human-interface-guidelines/accessibility

[3] Google. (2024). Material Design Accessibility Guidelines. Google Design. https://material.io/design/usability/accessibility.html

## 9.2. Indoor Navigation Research

[4] Sato, D., Oh, U., Guerreiro, J., Ahmetovic, D., Naito, K., Takagi, H., Kitani, K., and Asakawa, C. (2019). NavCog3 in the Wild: Large-scale Blind Indoor Navigation Assistant with Semantic Features. ACM Transactions on Accessible Computing, 12(3), Article 14.

[5] Ahmetovic, D., Gleason, C., Ruber, C., Kitani, K., Takagi, H., and Asakawa, C. (2016). NavCog: A Navigational Cognitive Assistant for the Blind. Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services, 90-99.

[6] Real, S., and Araujo, A. (2019). Navigation Systems for the Blind and Visually Impaired: Past Work, Challenges, and Open Problems. Sensors, 19(15), 3404.

## 9.3. Requirements Engineering

[7] van Lamsweerde, A. (2009). Requirements Engineering: From System Goals to UML Models to Software Specifications. Wiley.

[8] Wiegers, K., and Beatty, J. (2013). Software Requirements (3rd ed.). Microsoft Press.

[9] IEEE. (2011). ISO/IEC/IEEE 29148:2011 Systems and software engineering - Life cycle processes - Requirements engineering. IEEE Standard.

## 9.4. Computer Vision and Object Detection

[10] Redmon, J., and Farhadi, A. (2018). YOLOv3: An Incremental Improvement. arXiv preprint arXiv:1804.02767.

[11] Lin, T.Y., Goyal, P., Girshick, R., He, K., and Dollar, P. (2017). Focal Loss for Dense Object Detection. Proceedings of the IEEE International Conference on Computer Vision, 2980-2988.

## 9.5. Speech Recognition

[12] Hannun, A., Case, C., Casper, J., Catanzaro, B., Diamos, G., Elsen, E., Prenger, R., Satheesh, S., Sengupta, S., Coates, A., and Ng, A. Y. (2014). Deep Speech: Scaling up end-to-end speech recognition. arXiv preprint arXiv:1412.5567.

[13] Zhang, Y., Qin, J., Park, D. S., Han, W., Chiu, C.C., Pang, R., Le, Q. V., and Wu, Y. (2020). Pushing the Limits of Semi-Supervised Learning for Automatic Speech Recognition. arXiv preprint arXiv:2010.10504.

## 9.6. Mobile Development

[14] Android Developers. (2024). Android Accessibility Developer Guide. Google. https://developer.android.com/guide/topics/ui/accessibility

[15] Apple Developer. (2024). VoiceOver for iOS. Apple Inc. https://developer.apple.com/documentation/accessibility/voiceover