CptS 484: Software Requirements

WRS Evolution

Requirements Elicitation

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https://github.com/rk3026/Theia

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Revision History

Date	Version	Changes	Editor
10/8/2025	1.1	Migrate content from old template	All Team Members
10/12/2025	1.2	Completed missing sections and refinements	All Team Members
12/7/2025	1.3	Final review	Harry Ky

[1] Introduction

1.1 Purpose

The primary purpose of the Theia app is to provide indoor navigation for visually impaired individuals. It addresses the business' needs for a reliable, smartphone-based solution that allows them to move independently from one location to another within a building.

The app will assist users with critical navigation tasks like:

- Determining their current location.
- Identifying the correct direction to walk in.
- Knowing when and where to turn.
- Detecting obstacles to avoid collisions.
- Identify and aid users in emergency situations.

1.2 Scope

This project's scope is to develop the Theia mobile application, a solution designed for indoor navigation for blind or visually impaired users.

In Scope:

- Core Functionality: Providing turn-by-turn indoor navigation using a hybrid of pre-loaded building maps, phone sensors (IMU), and Bluetooth/Wi-Fi beacons.
- User Interface: An accessible interface primarily driven by voice commands, with a fallback to a compatible touch interface (VoiceOver for iOS, TalkBack for Android).
- Guidance: Delivering navigation instructions through audio cues and optional haptic feedback.
- Safety Features: Warning users of pre-mapped static obstacles (stairs, walls, etc.) and providing a user-triggered emergency communication feature.
- Platforms: The application will be developed for iOS and Android mobile devices.

Out of Scope:

- Outdoor navigation across streets, traffic, or open areas
- Detection of dynamic obstacles (moving people, vehicles)
- Within-room navigation (finding specific furniture or objects)
- Support for users with multiple severe disabilities beyond visual impairment

1.3 Objectives and Success Criteria

The main objective is that a user can consistently navigate a building independently and reliably. Caretakers have minimal effort and trouble setting up any necessary settings for the primary user. Building administrators can update building layout as needed upon building updates or temporary construction/ renovations. Emergency services can get a reliable location for the user in the case of a user needing assistance.

Our Success Criteria

- **Safety:** The app should detect and provide instructions to avoid **95%** of obstacles in a controlled testing environment.
- **Efficiency:** The app should guide a user to their destination along the fastest route with a navigation time within **5%** of the ideal travel time.

- **Usability:** The app should be easily usable for blind people, meaning all key functions, such as setting a destination, should be achievable through voice commands or tactile input with a **99%** success rate.
- **Accessibility:** The app complies with WCAG 2.1 Level AA standards and works seamlessly with platform accessibility features
- **Performance:** Route calculation completes within 3 seconds; real-time guidance updates with less than 1 second latency

1.4 Definitions, Acronyms, and Abbreviations

Term	Definition
Theia	Working name for the indoor navigation app.
IMU	Inertial Measurement Unit - combination of accelerometer, gyroscope, and magnetometer sensors
Static Obstacles	Fixed objects like walls, pillars, stairs that don't move
Dynamic Obstacles	Moving objects like people or vehicles (out of scope)
Dead Reckoning	Navigation method using IMU sensors to track position based on movement from a known starting point
Waypoint	A point along a route where navigation action is required (turn, enter elevator, etc.)
Haptic Feedback	Vibration patterns used to convey information non-verbally
WCAG	Web Content Accessibility Guidelines
AS / DE / CO	Identifiers for Assumption, Dependency, Constraint
TBD	To Be Determined: flags open issues that require clarification or decision in later project phases.
GPS	Global Positioning System (Not reliable indoors).
Bluetooth Beacons (iBeacon/Eddystone)	Small wireless transmitters installed in buildings that broadcast signals to nearby smartphones to assist with indoor positioning.
Accessibility API	Smart accessibility features such as Voiceover for iPhone and TalkBack for Android.

CAD (Computer Aided Design)	One of the most common formats that a building's basic floor plan or architectural files are found in. Two subsets of CAD files are DWG (short for 'drawing') and DXF (Drawing Interchange Format)
GIS (Geographic Information System)	An overarching term meant to cover any hardware or software-based system that plays a role in the creation, management, storage, or visualization of maps or geographical data

1.5 Overview

Issues and Resolutions

This section covers our initial analysis, where we resolved ambiguities in the project's domain, stakeholders, and requirements. We made key decisions on functional aspects, like sensor choice, and defined non-functional goals.

Requirements Specification (WRS)

Here, we present the formal Requirements Specification (WRS). This includes the core problem statement, project goals, and detailed lists of Functional Requirements (what the app does) and Non-Functional Requirements (it's essential qualities, like accuracy and privacy).

Preliminary Prototype and User Manual

This section provides a first look at the app through a visual mockup of the user interface and a basic user manual. It illustrates the app's core features and explains how to interact with it using voice and touch commands.

Traceability

Throughout the document, we ensure traceability by systematically mapping the project's logic. This involves linking user-identified problems to project goals, which are then connected to specific functional and non-functional requirements. These requirements are further translated into detailed specifications and prototype features, ensuring that every design decision is grounded in and traceable to user needs.

[2] Preliminary Definition

2.1. Preliminary Domain

PD_ID	Preliminary Domain Description
PD1	Stakeholder: A person with complete or near-complete loss of vision who needs to navigate indoors.
PD2	Stakeholder: Caretakers of the visually impaired, e.g. a family member
PD3	Stakeholder: Staff member in the accessibility department
PD4	Stakeholder: Police
PD5	Domain: Indoors, which can consist of multiple floors, each of which possibly hosts multiple classrooms, offices, bathrooms, lounges, elevators, etc.

2.2. Preliminary Functional Requirements

PFR_ ID	Preliminary FR Description
PFR1	Accepting from the user the destination location to go. It might even be able to suggest or confirm a possible destination location, utilizing the user's routine schedule or habit.
PFR2	Figuring out the routes to reach the destination, informing the user of the options (if there are more than one) and accepting user's preference.
PFR3	Telling the user to walk a distance (e.g., 2 minutes before turning, or walk for 30 steps, etc.)
PFR4	Telling the user to stop at the right place to turn.
PFR5	Detecting obstacles and telling the user what to do in order to avoid collision.
PFR6	Placing emergency calls and messages, possibly after detecting a fall or when the system has lost its current location.
PFR7	Figuring out what the next action(s) would be, based on the user's schedule or habit, and suggesting/accepting the user's choice.

2.3. Preliminary Non-Functional Requirements

PNFR_ ID	Preliminary NFR Description
PNFR1	The system shall help the user safely navigate indoors.
PNFR2	The system shall lead the user through the fastest route.
PNFR3	The system shall lead the user through the route that the user would feel the most comfortable with.
PNFR4	The system shall be usable for blind people.
PNFR5	The system shall be ubiquitous.
PNFR6	The system shall be customizable to every user: e.g. volume, the interval of instructions, etc.
PNFR7	The system shall be easily extensible to accommodate the following typical variations: variations in interface, language, definitive needs of the user, new features, new sensors and hardware, etc.

[3] Issues with the Preliminary Definition Given

3.1. Domain Issues

Domain Issue ID	Domain Issue Description	
DI1	**PD_ID**	PD1: A person with complete or near-complete loss of vision who needs to navigate indoors.

	Ambiguous. Does the person have any other disabilities that prevent them from using the phone and hearing instructions?	
	Option 1	Define the primary user as someone whose main challenge is visual impairment but who can hear, speak, and has the motor skills to use a smartphone's accessibility features
	Option 2	Expand the project's scope to design for users with multiple concurrent disabilities, such as being both deaf and blind or having severe motor impairments.
	Choice	Option 1
	Rationale	This choice sets a clear and achievable scope for the project. Designing for multiple complex disabilities, as suggested in Option 2, would require specialized hardware and interaction methods that are beyond the scope of this project.
Revised wording		4.1.3

Domain Issue ID	**Domain Issue Description**	
DI2	**PD_ID**	PD5. Domain: Indoors, which can consist of multiple floors, each of which possibly hosts multiple classrooms, offices, bathrooms, lounges, elevators, etc.
	1. The domain of ‘indoors’ is vague. 2. Different indoor environments (universities, malls, hospitals, airports) differ in complexity and accessibility. The domain says “different buildings that are connected to each other” but doesn’t explain how (hallways? tunnels? outdoor transitions?), which affects the scope. Can the app be used in every building, or only the ones that are mapped to floor plans? 3. The indoor environment has multiple aspects that can be approached differently e.g. stairs, elevators, and hallways can each have their own problems.	
	Option 1	Include hallways, tunnels, outdoor transitions, stairs, and elevators and treat them as separate domains.
	Option 2	Exclude the outdoor transitions entirely.
	Choice	Option 1
	Rationale	The system won’t have to change much to include the extra areas – possibly the outside areas could be avoided based on user preference. Nothing outside of a building though, meaning no traffic lights, road crossings. The outdoor area must be enclosed within a certain distance (for example, <=1600 sq.ft). Stairs and elevators can be treated as a separate domain from hallways, rooms, and

		outdoor transitions because they're navigated differently.
Revised wording		4.1.3

Domain Issue ID	Domain Issue Description	
DI3	**PD_ID**	PD2. Stakeholder: Caretakers of the visually impaired, e.g. a family member
	1. How will the caretaker be involved with the app? 2. Do they need to install the app to do things like creating building floor plans and config? Do they need a separate interface?	
	Option 1	Caretaker interface in app (click some button to go the config options)
	Option 2	Separate app or account for caretaker
	Choice	Option 1
	Rationale	Caretaker will go on the blind user's phone and configure the app themselves. This makes the one app the central place for configuration, avoiding complexity by having to manage communication between multiple app users.
Revised wording		4.1.3

Domain Issue ID	Domain Issue Description	
DI4	**PD_ID**	PD1, PD2, PD3, PD4
	1. Missing stakeholders: 2. Building administrators/facility managers (responsible for floor map accuracy). 3. App developers and maintainers (technical stakeholders). 4. Emergency responders other than police (paramedics, security staff).	
	Option 1	Include the other stakeholders in consideration.
	Choice	Option 1
	Rationale	We must include other stakeholders – building admins, developers, and emergency services.
Revised wording		4.1.3

3.2. Functional Requirements Issues

FR Issue ID	Description	
FRI1	**PFR_ID**	PFR1. Accepting from the user the destination location to go. It might even be able to suggest or confirm a possible destination location, utilizing the user's routine schedule or habit.

<table>
<tr><td></td><td colspan="2">1. How to accept a destination from the user?
2. The user needs to be able to give the system a destination, but they are visually impaired. How will they interact with the phone app to pick a destination?</td></tr>
<tr><td></td><td>Option 1</td><td>Voice Commands:
• Natural and fast for blind users
• Hands-free interaction
• Requires quiet environment / may struggle with background noise
• Speech recognition may misinterpret uncommon place names</td></tr>
<tr><td></td><td>Option 2</td><td>Touch (screen-based, accessible UI):
• Works in noisy environments or when voice is uncomfortable
• Can leverage accessibility features (e.g., screen readers and haptic feedback)
• Slower than voice for many users
• Requires careful accessible design (large buttons, logical layout)</td></tr>
<tr><td></td><td>Option 3</td><td>Hybrid (Options 1 + 2)
• Voice Commands (option 1) as primary
• Touch (option 2) as fallback</td></tr>
<tr><td></td><td>Choice</td><td>Option 3</td></tr>
<tr><td></td><td>Rationale</td><td>Support both voice commands and touch input. Default to voice commands as the primary mode, since they are the most natural and efficient for blind users, while providing a well-designed accessible touch fallback for situations where voice is impractical (e.g., noisy environments, privacy concerns).</td></tr>
<tr><td>Satisfied by</td><td colspan="2">FR1, FR2</td></tr>
</table>

<table>
<tr><th>FR Issue ID</th><th colspan="2">Description</th></tr>
<tr><td>FRI2</td><td>PFR_ID</td><td>PFR2. Figuring out the routes to reach the destination, and informing the user of the options (if there are more than one), and accepting user’s preference.</td></tr>
<tr><td></td><td colspan="2">1. How to determine routes?
2. The routing algorithm involved will have to utilize sensors – which ones should the app use.</td></tr>
<tr><td></td><td>Option 1</td><td>GPS:
• Works outdoors, integrates with existing navigation apps</td></tr>
</table>

		• Very inaccurate indoors (often 5–10m error, unusable in hallways/rooms)
	Option 2	Building Mapping (digital indoor maps with predefined pathways): • Accurate indoors if maps are available • Allows step-by-step turn guidance • Requires upfront mapping effort or access to existing digital building data • May become outdated if building layout changes
	Option 3	Beacon-based (Bluetooth/Wi-Fi positioning): • Can provide location anchors to correct dead reckoning drift • Needs infrastructure (beacons, calibration, maintenance)
	Option 4	Dead Reckoning with IMU (accelerometer, gyroscope, magnetometer): • Works without infrastructure once starting position is known • Low energy usage • Drift accumulates over time, needs correction via anchors/maps
	Option 5	Hybrid - combine building mapping with dead reckoning (IMU) as the core method and enhance accuracy with Bluetooth/Wi-Fi beacons where available. GPS is only used for outdoor-to-indoor transitions.
	Choice	Option 5
	Rationale	• GPS alone is insufficient indoors. • A hybrid of indoor maps + IMU ensures robust routing without requiring constant infrastructure. • Beacons (when present) can improve precision, but the system should still function without them.
Satisfied by	FR9	

FR Issue ID	**Description**	
FRI3	**PFR_ID**	PFR3. Telling the user to walk a distance (e.g., 2 minutes before turning, or walk for 30 steps, etc.)
	1. How to tell the user what to do to follow the route?	

	2. The system must tell the user to walk a distance or stop at certain points. How will the system provide the user with these instructions?	
	Option 1	Audio Instructions (distance-based): • Natural for blind users; hands-free • Can give precise directions (“Walk 10 meters, then turn left”) • Distance estimation may be hard for some users to judge without feedback
	Option 2	Audio Instructions (step-based): • Aligns with the way many blind users count steps • Reduces ambiguity if step length is known • Step counting may drift (different stride lengths, uneven walking)
	Option 3	Haptic Feedback (vibration cues): • Can reinforce directions non-verbally (e.g., buzz for “turn left/right”) • Useful in noisy environments • May be too subtle or confusing if overused
	Option 4	Hybrid - Use audio instructions as the primary method, with both distance-based and step-based phrasing. User preference can decide haptic feedback or if the voice commands are silenced.
	Choice	Option 4
	Rationale	Audio is the most accessible and clear for blind users, but flexibility is key: some users prefer step-based cues, while others find distances easier. Haptics serve as a backup channel in noisy environments or in order to reinforce important cues.
Satisfied by	FR3, FR4, FR6	

FR Issue ID	**Description**	
FRI4	**PFR_ID**	PFR5. Detecting obstacles and telling the user what to do in order to avoid collision.
	1. How to detect obstacles on the route? 2. Phone GPS probably is not effective inside a building.	
	Option 1	Phone Camera (computer vision for obstacle detection / Apriltags): • Can recognize obstacles and markers with high precision

		• Apriltags can provide reliable positioning indoors if posted in the environment • Continuous camera use drains battery and raises privacy concerns • Requires cooperation from building managers (posting/maintaining Apriltags)
	Option 2	Phone’s Built-in Sensors (LiDAR / Depth on supported devices): • Detects nearby obstacles in real time without special markers • Useful for dynamic obstacles (people, furniture) • Only available on certain devices; can drain battery
	Option 3	Crowdsourced / Map-based Obstacles: • Relies on pre-mapped known obstacles (walls, fixed furniture) • Very low power consumption • Cannot handle dynamic obstacles (people, temporary barriers)
	Option 4	Wearable or Accessory Integration (e.g., smart cane with sensors): • Offloads obstacle detection to a specialized device • More reliable for real-time avoidance • Requires additional hardware, not just a phone app.
	Choice	Hybrid - rely primarily on building maps for static obstacles, while enabling camera-based Apriltag detection (or depth sensors where available) to refine positioning and detect unexpected obstacles. Dynamic obstacle detection should be left to the user’s existing mobility aids (e.g., cane or guide dog), with Theia providing route guidance rather than full obstacle avoidance.
	Rationale	• Phone GPS is unreliable indoors. • Map data ensures predictable, static obstacle awareness. • Camera-based Apriltags (if buildings cooperate) provide accurate localization with minimal infrastructure.

		• Continuous real-time obstacle detection via phone camera or LiDAR would be battery-heavy and privacy-sensitive, so it should be event-triggered or supplemental, not always-on. • Sound effects can be used when close to obstacle
Satisfied by	FR7	

FR Issue ID	**Description**	
FRI5	**PFR_ID**	PFR6. Placing emergency calls and messages, possibly after detecting a fall or when the system has lost its current location.
	1. When/How to place emergency calls and messages? 2. Emergency calls and messages must be placed to help a user if they are in danger. But when should these calls and messages be placed? The user should have some control over the situation to avoid accidental calls when not needed.	
	Option 1	Phone Collision Detection / Fall Detection • Can automatically detect dangerous situations (e.g., falls or sudden impact) • Hands-free for the user in emergencies • Risk of false positives (e.g., dropping phone accidentally) • Some situations may not involve a detectable collision
	Option 2	Large On-Screen Emergency Button • Gives the user full control to trigger calls/messages • Reduces false alarms • Requires the user to access the phone, which may be difficult in certain emergency scenarios
	Option 3	Hybrid • Automatic detection triggers a confirmation prompt via audio or vibration • User can confirm or cancel the emergency call/message • Large on-screen button remains available for manual emergencies
	Choice	Option 3
	Rationale	• Blind users must have control to prevent accidental calls.

		• Automatic detection improves safety when the user cannot access the phone immediately. • A combined system ensures reliability, usability, and safety while minimizing false positives.
Satisfied by	FR10, FR11	

FR Issue ID	**Description**	
FRI6	PFR_ID	PFR7. Figuring out what the next action(s) would be, based on the user's schedule or habit, and suggesting/accepting the user's choice.
	1. What are the 'next action(s)' the system will provide based on user schedule? 2. After routing, the system should continue to provide help to the user with some actions, but what should these be?	
	Option 1	Remind About Upcoming Appointments / Tasks • Provides contextual assistance based on the user's schedule • Helps the user stay on track without needing to check a calendar • Requires integration with calendar apps or manual schedule entry
	Option 2	Suggest Next Steps in Route / Navigation • Guides the user seamlessly from one location to another (e.g., after finishing one task, direct to the next destination) • Reduces cognitive load for blind users • Depends on accurate location tracking
	Option 3	Contextual Alerts or Recommendations • Notify about environment-related actions (e.g., "Elevator nearby," "Door is closed") • Can adapt dynamically to current surroundings • Must balance information overload vs. useful guidance
	Option 4	Safety or Health Reminders • Gentle prompts for hydration, breaks, or obstacle awareness • Could be perceived as intrusive if too frequent
	Choice	Option 2
	Rationale	The app is primarily a navigation app. Scheduling is a large scope, and adds much complexity on for a optional feature.

Satisfied by	FR5

FR Issue ID	**Description**	
FRI7	**PFR_ID**	PFR2. Figuring out the routes to reach the destination, and informing the user of the options (if there are more than one), and accepting user's preference.
	1. How are elevators / stairs handled? 2. Not all buildings have elevators or slopes. Stairs may be difficult for the user and the system.	
	Option 1	Warnings on elevators and stairs
	Option 2	Avoid stairs while routing
	Option 3	Offer alternate routes on preference.
	Choice	Option 1
	Rationale	The app should offer configuration modes that the user/caretaker can change if the user has difficulty with stairs. Default option should be warnings, but the preferences should be configured in settings.
Satisfied by	FR7, FR8, FR9	

FR Issue ID	**Description**	
FRI8	**PFR_ID**	PFR1. Accepting from the user the destination location to go. It might even be able to suggest or confirm a possible destination location, utilizing the user's routine schedule or habit.
	1. How destinations/maps are inserted into the system?	
	Option 1	The app provides interface for caregivers to scan the floor plans of the buildings. The system will process and convert the floor plans into virtual indoor maps
	Option 2	The app provides a separate client interface for third-party personnel (e.g. building staff) to upload floor plans to the system.
	Option 3	The system queries the building's floor plans on the internet based on user's location.
	Option 4	Caretakers model the floor plans
	Option 5	THEIA staff create the floor plans
	Choice	Option 1
	Rationale	Most practical and economical. This option requires minimal expertise from users and minimal involvement from third parties.
Satisfied by		

FR Issue ID	Description	
FRI9	**PFR_ID**	PFR7. Figuring out what the next action(s) would be, based on the user's schedule or habit, and suggesting/accepting the user's choice.
	1. How to track user preferences, schedule?	
	Option 1	Save list of previous destinations in local storage (cons of privacy?)
	Option 2	Favorites Destinations – user can add destinations/locations to favorites
	Option 3	User profile system
	Option 4	Cloud sync across devices (also privacy concerns)
	Option 5	Context-Aware (based on time of day, location)
	Option 6	Integration w/ Third Party apps (calendar, etc.)
	Choice	Option 1,2
	Rationale	Option 1 provides an efficient way to predict user's next locations, the other options require the overhead of an account system or addition ui for login and user preferences. Online storage also has privacy concerns that require additional protection. Option 2 provides manual entry of preferred locations for additional preference and customizability.
Satisfied by		

3.3. Non-Functional Requirements (NFR) Issues

NFR Issues ID	Description	
NFRI1	**PNFR_ID**	PNFR1. The system shall help the user safely navigate indoors.
	1. How to help user 'safely' navigate indoors? 2. How do we define 'safely'?	
	Option 1	Avoid Obstacles • Warn users about static obstacles (walls, furniture, doors) • Warn users about dynamic obstacles (people, temporary barriers) • Real-time dynamic detection may require additional sensors or infrastructure
	Option 2	Avoid Dangerous Areas • Elevators, stairs, ramps, or restricted areas

		• Can integrate with accessible route planning • Requires accurate building maps and accessibility data
	Option 3	Provide Contextual Guidance • Step-by-step audio or haptic cues to ensure correct direction • Reduce risk of user veering off safe paths • May require precise location tracking to be effective
	Option 4	Hybrid (All of the above)
	Choice	Option 4
	Rationale	All options make navigation safer. Safety should be a priority.
Satisfied by	NFR1, NFR3	

NFR Issues ID	**Description**	
NFRI2	**PNFR_ID**	PNFR2. The system shall lead the user through the fastest route.
	1. How to determine the ‘fastest’ route? 2. What makes a route the ‘fastest’?	
	Option 1	Shortest Distance Route • Simple to compute using building maps and known pathways • Works for general navigation • May not account for obstacles, stairs, or accessibility constraints that slow the user down
	Option 2	Estimated Travel Time • Takes user mobility, obstacles, stairs/elevators, and route type into account • More realistic measure of speed than pure distance • Requires knowledge of user’s walking speed and environmental conditions
	Option 3	Hybrid (1+2)
	Choice	Option 3

	Rationale	Should be the shortest travel time while factoring the user preferences into account (whether to avoid stairs, outdoors, etc.).
Satisfied by	NFR2	

NFR Issues ID	**Description**	
NFRI3	**PNFR_ID**	PNFR3. The system shall lead the user through the route that the user would feel the most comfortable with.
	1. How to determine the route that is the 'most comfortable' for the user? 2. What makes a route comfortable?	
	Option 1	Avoid stairs or elevators, outdoors, specific rooms, and crowded areas.
	Option 2	Settings for configuring route preferences
	Option 3	Present multiple route options when selecting a destination
	Option 4	Hybrid (1+2+3)
	Choice	Option 4
	Rationale	Allow user configurations as well as selecting a route from various options. This gives the user the most customizability to fit their comfort level while traveling.
Satisfied by	NFR2, FR8, FR9	

NFR Issues ID	**Description**	
NFRI4	**PNFR_ID**	PNFR1-3.
	1. How to balance safety, speed, and comfort? 2. There are tradeoffs between safety, speed, and comfort.	
	Option 1	Prioritize one of the three
	Option 2	User configuration
	Option 3	Weighted criteria
	Option 4	Option 1, then Hybrid (2+3)
	Choice	Option 4
	Rationale	Safety should come first; nothing should sacrifice safety. Speed and comfort can be user configured or at the time the user picks a route.
Satisfied by	NFR4	

NFRI5	**PNFR_ID**	PNFR4. The system shall be usable for blind people.
	1. How to make the system ‘usable’ for blind people? 2. What does usable mean for the system? What metrics?	
	Option 1	Compliance with accessibility standards (WCAG, ADA)
	Option 2	Metrics: • Task completion rate (can users reach destinations successfully?) • Time to complete tasks/routes • Error rate (missed turns, collisions) • User satisfaction surveys or qualitative feedback
	Option 3	Hybrid (1+2)
	Choice	Option 3
	Rationale	Accessibility standards can provide helpful information for design, and metrics are necessary for measuring completeness / success.
Satisfied by	NFR5	

NFR Issues ID	**Description**	
NFRI6	**PNFR_ID**	PNFR5. The system shall be ubiquitous.
	1. How to make the system ‘ubiquitous’? 2. What does ubiquitous mean for the system?	
	Option 1	Support multiple mobile OS
	Option 2	Minimal/Low hardware requirements
	Option 3	Minimal dependency on external infrastructure and internet connection
	Option 4	Hybrid (all)
	Choice	Option 4
	Rationale	All these options will provide us with better ubiquity – expanding the possible user base. Improve availability and reliability
Satisfied by	NFR4	

NFR Issues ID	**Description**	
NFRI7	**PNFR_ID**	PNFR6. The system shall be customizable to every user: e.g. volume, the interval of instructions, etc.

	1. How to make the system 'customizable' to every user? 2. What metrics for customizable?	
	Option 1	User interface customizability (colors, layout, text size, etc.)
	Option 2	Route preference
	Option 3	Metrics for Customization: • Frequency of preference changes (how often users adjust settings) • Task performance under different settings (success rate, travel time) • User satisfaction with personalization
	Option 4	Hybrid (all)
	Choice	Option 4
	Rationale	Ensure UI can be customized and various route options, as well as clarify the metrics for customization and ensure they are met.
Satisfied by	NFR5, NFR6, NFR7, FR8	

NFR Issues ID	**Description**	
NFRI8	**PNFR_ID**	PNFR7. The system shall be easily extensible to accommodate the following typical variations: variations in interface, language, definitive needs of the user, new features, new sensors and hardware, etc.
	1. How to make the system 'easily extensible'? 2. System should accommodate variations in interface, language, definitive needs of user, new features, sensors and hardware, etc.	
	Option 1	Modular design
	Option 2	API/plugin-based
	Option 3	Localization support
	Option 4	Configuration settings
	Option 5	Hybrid (all)
	Choice	Option 5
	Rationale	Make Theia easily extensible through a modular architecture with well-defined APIs, support for internationalization/localization, and configurable user profiles. New sensors, features, or interface variations can be added as separate modules without impacting the core system.
Satisfied by	NFR7, NFR8	

[4] WRS

4.1. W

This section defines the problems, goals, and improved understanding of the domain, functional objectives, and non-functional objectives.

4.1.1. Problem

Overarching problem – help visually impaired people navigate indoors. The table breaks this problem down into several smaller problems that lead to concrete goals.

Problem ID	Problem Description	Corresponding Goals
P1	**Accessibility & UX** – How to efficiently communicate with blind people through a smartphone app?	G2, G8
P2	**Navigation** – How to compute the safest, most efficient route to an indoor destination?	G4
P3	**Navigation** – How to create/design usable floor plans of buildings?	G4
P4	**User Input and Preferences** – What configuration settings should be available?	G6
P5	**Sensing & Data Gathering** – What sensors to use to avoid obstacles, determine position, and detect falls?	G1
P6	**Privacy & Trust** – How to handle user information and keep the app trustworthy?	G1, G10
P7	**Scalability & Deployment** – How to allow for many users without the system failing?	G5, G7
P8	**Accessibility & UX** – How do caregivers help configure the app?	G2, G6
P9	**Safety** – How is "emergency" situation/scenario determined?	G3
P10	**Navigation** – What is the difference between floor vs. stair navigation?	G9
P11	**Navigation** – What actions are involved in navigating? Run, jog, walk x steps, take elevator, take stairs, move x distance, turn, wait, etc.	G8

P12	**Domain** – What are the characteristics of the primary user? Visually impaired, but what other possible?	G2, G4, G8
P13	**Accessibility & UX** – How can the user configurate preferred location or schedule?	G4, G6
P14	**Safety** – What are "obstacles"? How are obstacles detected?	G10, G1
P15	**Storage** – How to upload/store building floor plans?	G11
P16	**Storage** – How to store user schedule and habits?	

4.1.2. Goals

These are the goals that address the problems in the previous section. They eventually lead to requirements specification, both functional and non-functional. Figure 1 is a KAOS model of the initial goal of providing indoor navigation for visually impaired users. This top-level goal is broken down into several other goals that lead to functional and non-functional requirements.

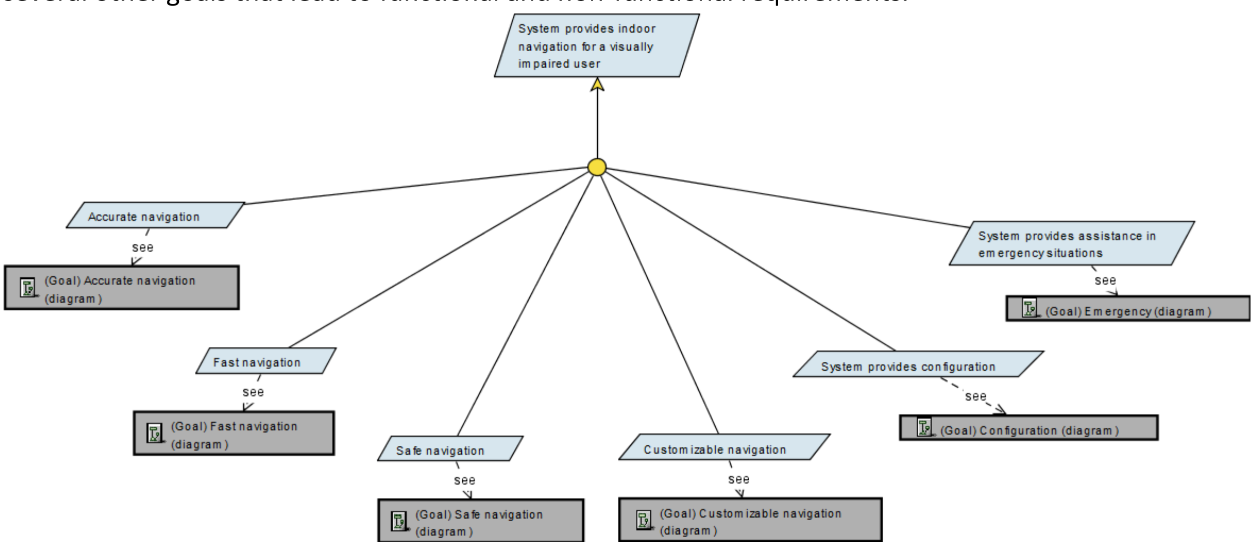

Figure 1. Goal: System provides indoor navigation for a visually impaired user

Goal ID	**Goal Description**	**Backward Traceability**	**Forward Traceability**
G1	Use phone's built-in capabilities and sensors for navigation and fall detection	P5	IFRO1, IFRO2, IFRO4
G2	Provide a configurable interface for caregivers	P1, P8	IFRO8
G3	Provide help in case of emergency	P9	IFRO5

G4	Provide several route options based on speed vs. comfortability	P2, P13	IFRO2, IFRO6
G5	Make the app support multiple mobile operating systems (Android/iOS)	P7	NFR4
G6	Provide configurable settings for voice commands, route preferences, haptics, etc.	P4, P13	IFRO7, FR8
G7	Make the app have minimal hardware requirements	P7	NFR4
G8	Provide navigation indoors with voice instruction and haptics	P1, P11	IFRO3
G9	Navigation between floors by taking stairs, slopes, or elevators	P10	IFRO7
G10	Classify static objects in the navigation path into different categories to alert user	P14	IFRO4
G11	Persistent floorplan management	P15	IFRO8
G12	Persistent user preference & habits management	P16	IFRO9

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

4.1.3.1. Improved Domain

Improved Domain ID	**Improved Domain Description**
ID1	Stakeholders: • Primary user: Visually impaired, can read and speak English, reasonably familiar with the building, existing experience using smartphone with accessibility functions, such as pressing home, buttons, volume buttons, and making voice command to the smartphone. Might be using other tools (cane/dog). Able to use stairs/elevator • Caregivers: They are familiar with regular usage of a smartphone app. They can hear, understand, and speak English. Can contact their client. • Family members • Emergency responders • Building admins in accessibility department • System developers • API providers • Regulatory bodies for the visually impaired

ID2	Indoor rooms and level transitions between rooms. • Indoor spaces which include hallways, skybridges, and rooms. • Outdoor transitions (paved pathways) • Courtyards (~1600 sq. ft) • NO crosswalks • NO traffic lights • Only deal with static obstacles, NO detection of moving obstacles
ID3	Stairs, elevators, and escalators providing a transition between the spaces defined in ID2.

4.1.3.2. Stakeholders

Stakeholder list:

- Visually impaired
- Caregivers
- family members
- emergency responders
- building admins in accessibility department
- system developers
- API providers
- Regulatory bodies for the visually impaired

4.1.3.3. 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 accept user destination input via voice command or accessible touch interface	P1	G2, G8
IFRO2	Theia shall compute indoor routes using a hybrid method that combines digital building maps with IMU-based dead reckoning, enhanced by Bluetooth/Wi-Fi beacons where available, and GPS only for outdoor transitions.	P2, P3, P5	G1, G4
IFRO3	Theia shall deliver navigation instructions primarily through audio, supporting both distance- and step-based cues, with optional haptic feedback based on user preference.	P1, P11	G6, G8
IFRO4	Theia shall detect and warn users of static obstacles using pre-mapped data, and optionally refine detection with camera or depth sensors where available	P5, P14	G1, G10

IFRO5	Theia shall enable emergency communication through a large accessible SOS button and automatic fall detection that prompts the user to confirm before sending alerts	P9	G3
IFRO6	Theia shall suggest and guide users to their next destination based on prior routes or routine navigation patterns.	P12, P13	G4, G6
IFRO7	Theia shall notify users when approaching stairs or elevators, with configurable preferences for accessibility and safety	P10	G6, G9
IFRO8	Theia shall allow a caretaker to manage the floorplans associated with a visually impaired user.	P15	G11
IFRO9	Theia shall allow a visually impaired user to favorite destinations and track their previous locations locally.	P16	G12

4.1.3.4. Improved Non-Functional Objectives

Improved NFR Objective ID	Objective Description	Alleviates Problem	Achieves Goal
INFRO1	The system shall help the user accurately navigate indoors and avoid obstacles and dangerous area	P1, P14	G1, G8
INFRO2	The system shall lead the user through the shortest and least time-consuming route	P2	G4, G6
INFRO3	The system shall lead the user through the route that user selected or configured in their preferences	P4, P13	G4, G6
INFRO4	The system shall prioritize user safety when computing a route	P9, P10	G3, G9
INFRO5	The system shall comply with accessibility standard and adapt to personalized user pattern	P1, P8	G2, G6
INFRO6	Theia is available and dependable for a variety of mobile devices	P1	G2, G6
INFRO7	The system shall provide a customizable UI	P1, P4	G2, G6
INFRO8	The system shall be easily extensible through a modular architecture with well-defined APIs, support for	P7	G5, G7

	internationalization/localization, and configurable user profiles.		

4.2. RS

4.2.1. Functional Requirements

In this section, Functional Objectives are refined into concrete functional requirements. Each FR corresponds to an implementable feature in the app. Figures 2, 3, and 4 are KAOS models of goals that correspond to functional requirements for the app.

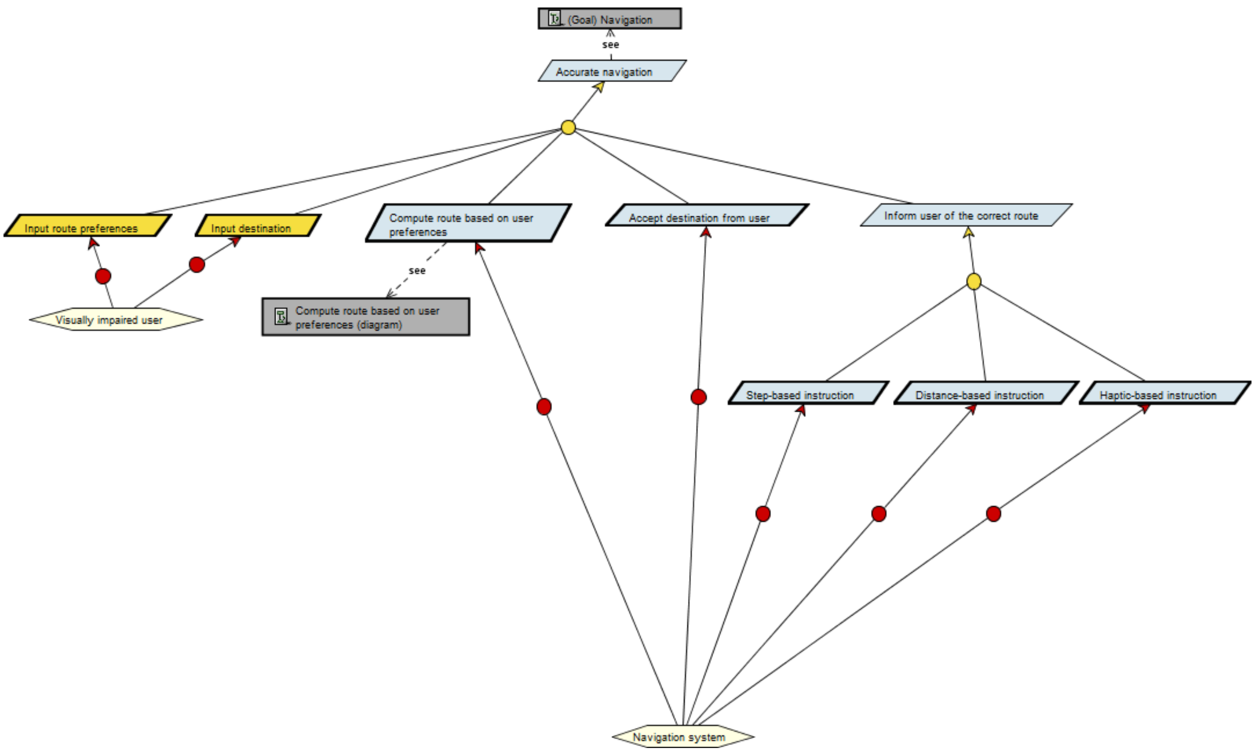

Figure 2. Goal: Accurate navigation

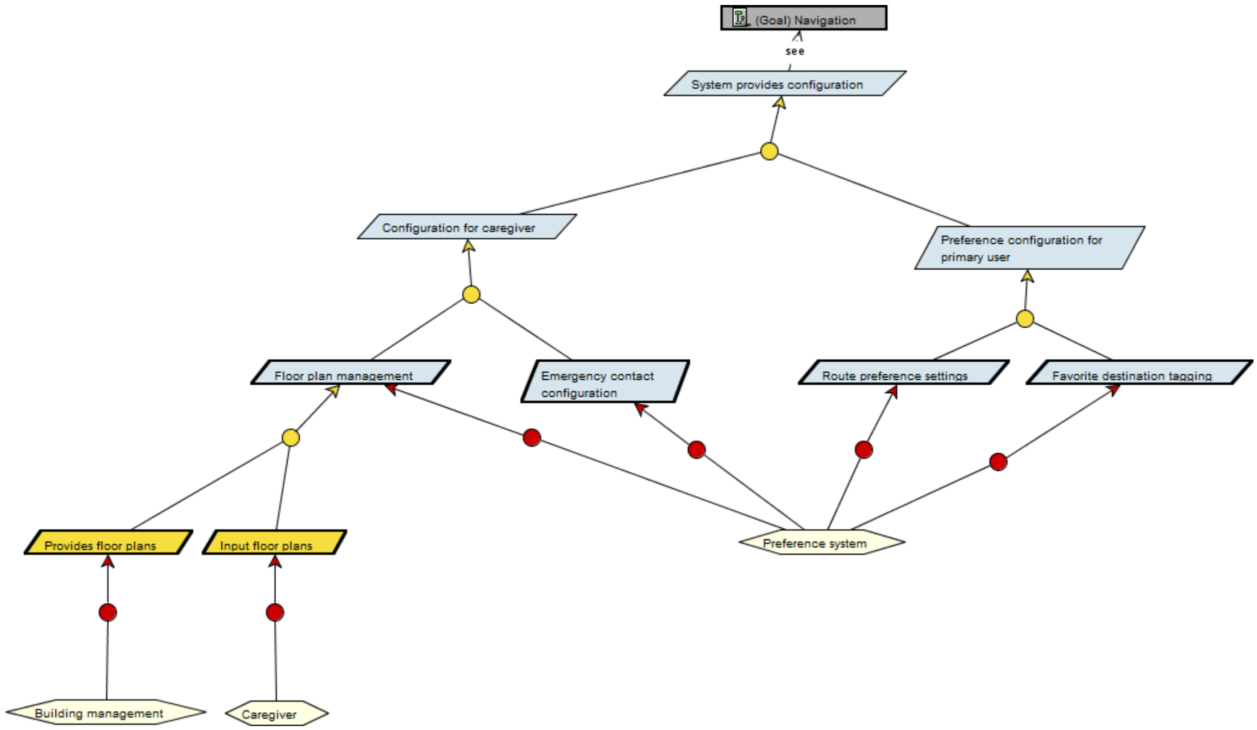

Figure 3. Goal: System provides configuration

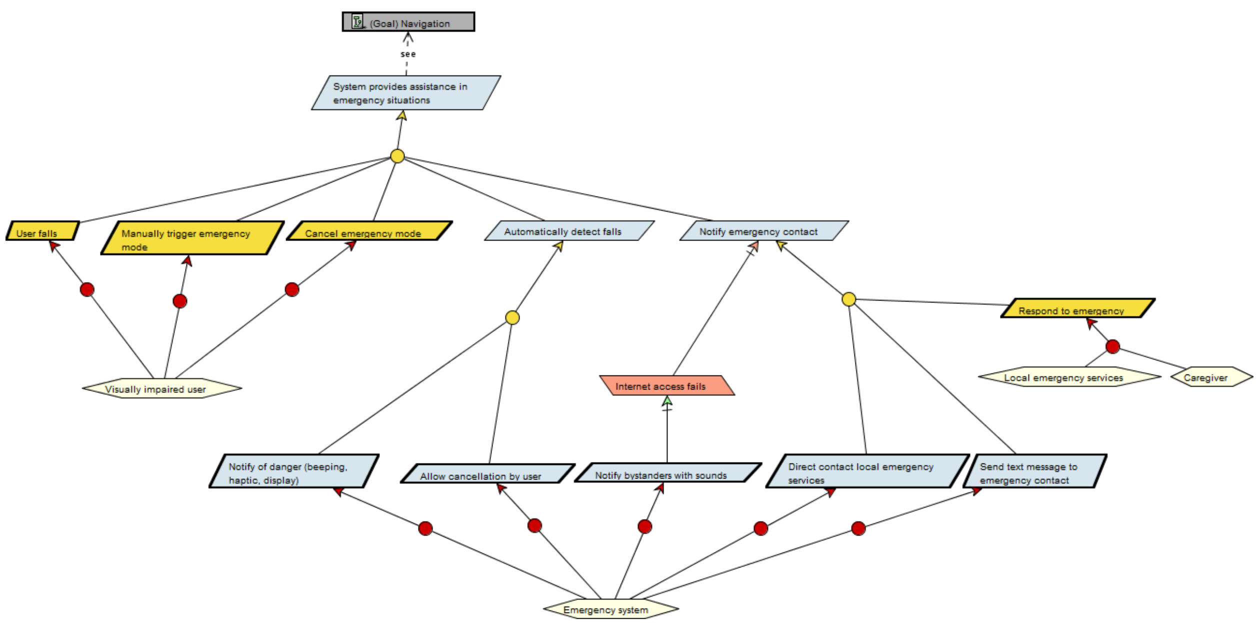

Figure 4. Goal: System provides assistance in emergency situations

FR ID	Description
FR1	Accept destination input from Voice command.
Satisfies Functional Requirement Issue	FRI1, NFRI5
Satisfies Objectives	IFRO1, INFRO5
Satisfied by prototype feature	Destination Selection

FR ID	Description
FR2	Accept destination input from Accessible Touch Interface.
Satisfies Functional Requirement Issue	FRI1, NFRI5
Satisfies Objectives	IFRO1, INFRO5
Satisfied by prototype feature	Destination Selection

FR ID	Description
FR3	Provide audible guidance to communicate navigation instruction.
Satisfies Functional Requirement Issue	FRI3, NFRI5
Satisfies Objectives	IFRO3, INFRO5
Satisfied by prototype feature	Navigation Instruction

FR ID	Description
FR4	Provide haptics to communicate navigation instructions.
Satisfies Functional Requirement Issue	FRI3, NFRI5
Satisfies Objectives	IFRO3, INFRO5
Satisfied by prototype feature	Navigation Instruction

FR ID	Description
FR5	Provide suggestions for next destinations to navigate to based on location history and favorites.

Satisfies Functional Requirement Issue	FRI6
Satisfies Objectives	IFRO6
Satisfied by prototype feature	Destination Selection

FR ID	**Description**
FR6	Provide a navigation mode that gives step-by-step instructions.
Satisfies Functional Requirement Issue	FRI3, FRI4, NFRI1
Satisfies Objectives	INFRO1, IFRO3, INFRO3
Satisfied by prototype feature	Navigation Instruction

FR ID	**Description**
FR7	System warns user when approaching static obstacles and stairs.
Satisfies Functional Requirement Issue	FRI4
Satisfies Objectives	INFRO1, IFRO4
Satisfied by prototype feature	Navigation Instruction

FR ID	**Description**
FR8	System provides a configuration menu that exposes settings for navigation preferences, audio, and haptics
Satisfies Functional Requirement Issue	NFRI7, NFRI8, FRI6
Satisfies Objectives	INFRO7, INFRO8
Satisfied by prototype feature	Configuration menu

FR ID	**Description**

FR9	System calculates a variety of different route options based on speed, distance, avoidance settings, or level of accessibility.
Satisfies Functional Requirement Issue	FRI2
Satisfies Objectives	IFRO2
Satisfied by prototype feature	Route Computation

FR ID	**Description**
FR10	System provides fall detection.
Satisfies Functional Requirement Issue	FRI5
Satisfies Objectives	IFRO5
Satisfied by prototype feature	Fall Detection

FR ID	**Description**
FR11	System provides automatic contact of emergency services in case of emergency
Satisfies Functional Requirement Issue	FRI5
Satisfies Objectives	IFRO5
Satisfied by prototype feature	Emergency Procedure

FR ID	**Description**
FR12	System provides a local database for storing floorplans that the visually impaired user is navigating.
Satisfies Functional Requirement Issue	FRI8
Satisfies Objectives	IFRO8
Satisfied by prototype feature	Upload floor plan

FR ID	Description
FR13	System provides a local database for storing destination history and user favorite locations.
Satisfies Functional Requirement Issue	FRI9
Satisfies Objectives	IFRO9
Satisfied by prototype feature	Favorite locations and travel history

FR ID	Description
FR14	System provides a UI for entering in favorite locations.
Satisfies Functional Requirement Issue	FRI9
Satisfies Objectives	IFRO9
Satisfied by prototype feature	Favorite locations and travel history

4.2.2. Non-Functional Requirements

The non-functional objectives are refined into non-functional requirements for the app. Figures 5, 6, and 7 show KAOS models of the goals that are refined into non-functional requirements.

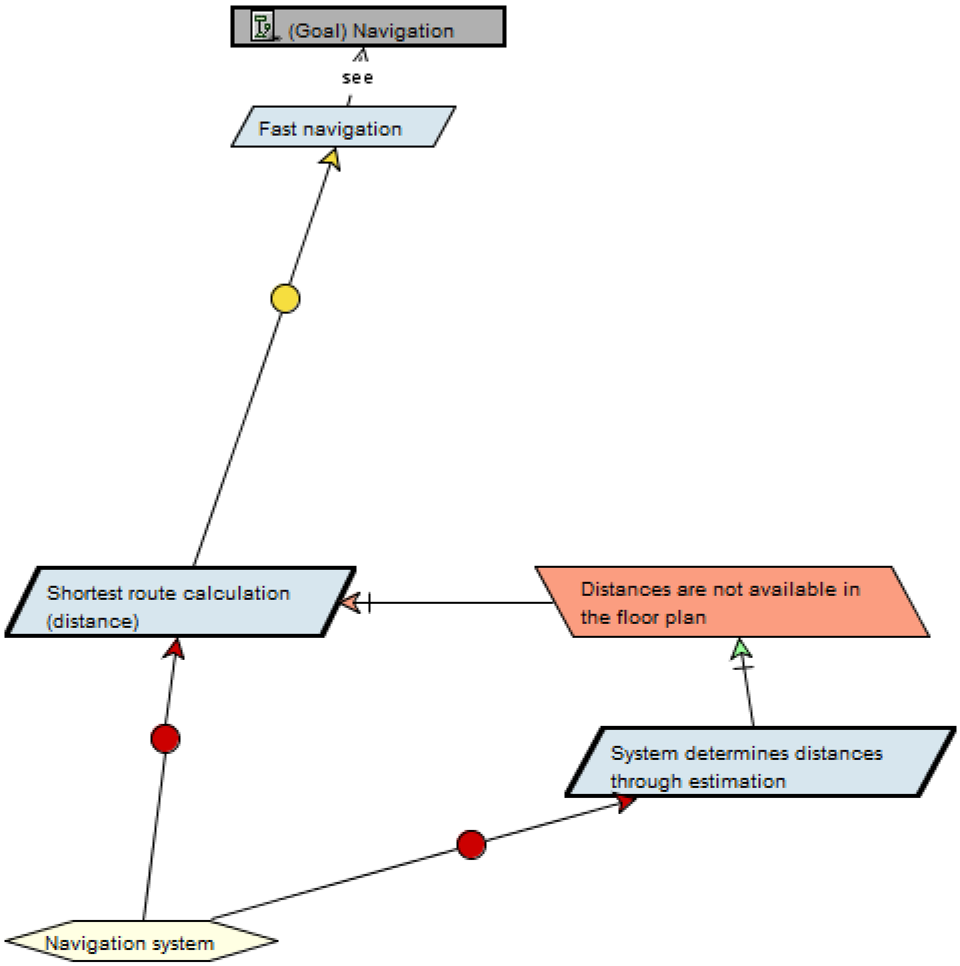

Figure 5. Goal: Fast navigation

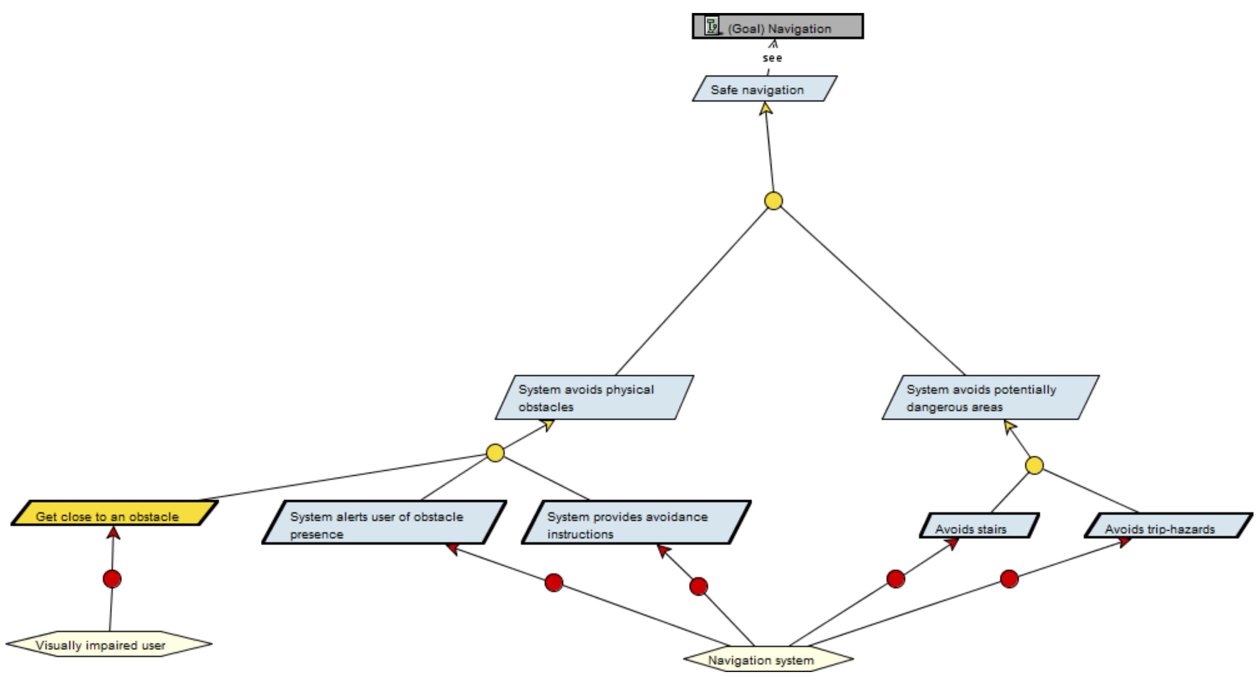

Figure 6. Goal: Safe navigation

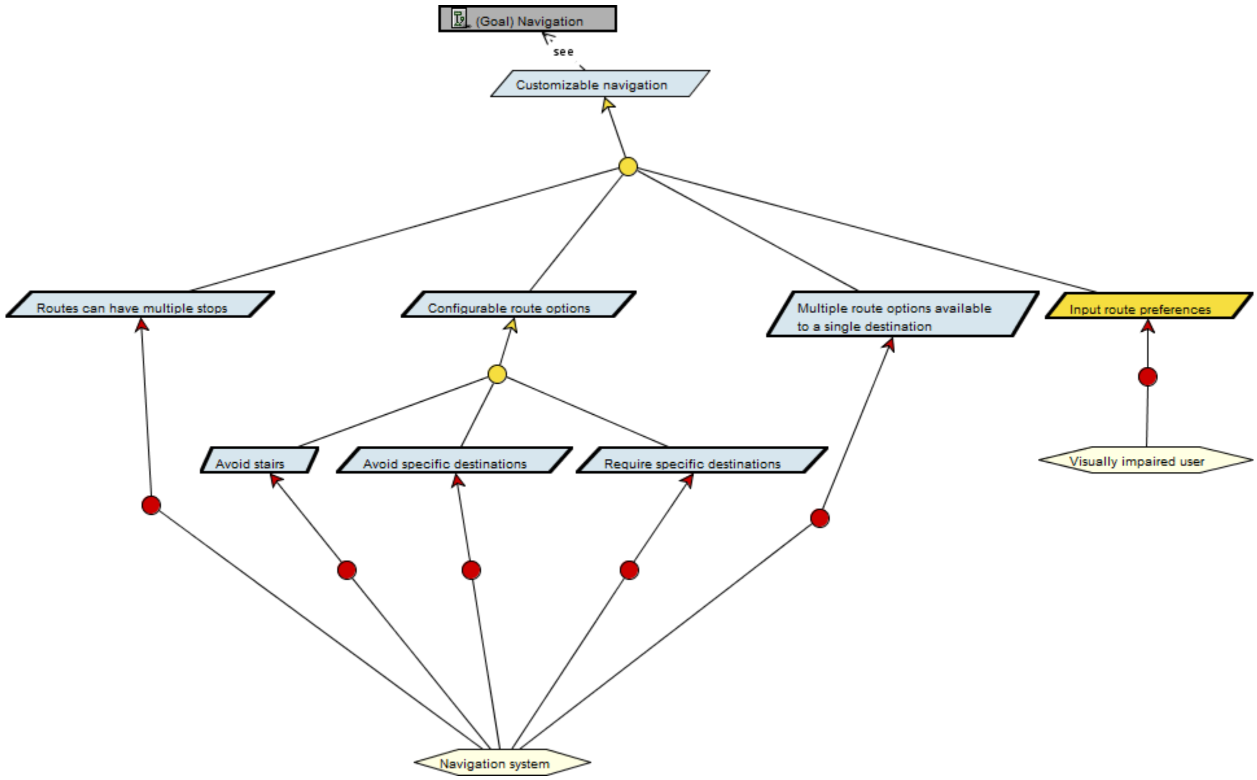

Figure 7. Goal: Customizable navigation

NFR ID	**Nonfunctional Requirement 1**
NFR1	Navigation instructions are given through voice commands AND haptics. The haptics include vibration when reaching a navigation waypoint (i.e, "Turn Right"), and vibration patterns when approaching dangers like obstacles or stairs.
Operationalized Functional Requirements	FR3, FR4, FR6, FR7
Satisfies Nonfunctional Requirement Issue	NFRI1, NFRI5
Satisfies Non-functional Objective	INFRO1, INFRO5
Constrains	P1, P5
Satisfied by prototype feature	Navigation Instruction

NFR ID	**Nonfunctional Requirement 2**
NFR2	Routes take the shortest path possible after considering the route preferences and avoidance options.
Operationalized Functional Requirements	FR9

Satisfies Nonfunctional Requirement Issue	NFRI2, NFRI3, NFRI4
Satisfies Non-functional Objective	INFRO2, INFRO3
Constrains	P2, P4, P13
Satisfied by prototype feature	Route Computation, Route Selection

NFR ID	**Nonfunctional Requirement 3**
NFR3	The system audibly/haptically warns a user at least 10 seconds before reaching an obstacle.
Operationalized Functional Requirements	FR3, FR4, FR7
Satisfies Nonfunctional Requirement Issue	NFRI1
Satisfies Non-functional Objective	INFRO1, INFRO4
Constraints	P5, P14
Satisfied by prototype feature	Navigation Instructions

NFR ID	**Nonfunctional Requirement 4**
NFR4	The system has broad support on both Android and iOS: • Android: support Android 9 (API 28) and above • iOS: support iOS 13 and above (covers many older devices while still supporting modern APIs like CoreML/ARKit where available).
Operationalized Functional Requirements	N/A (it's a system-wide constraint, not operationalizing specific FRs)
Satisfies Nonfunctional Requirement Issue	NFRI6
Satisfies Non-functional Objective	INFRO6, INFRO8
Constrains	P1, P7
Satisfied by prototype feature	N/A (same reason as operationalized functional requirements)

NFR ID	**Nonfunctional Requirement 5**
NFR5	The system UI consists of well-organized, large buttons and UX is haptic-based with Screen-Reader compatibility (VoiceOver on iOS, TalkBack on Android)
Operationalized Functional Requirements	FR1, FR2, FR4, FR8

Satisfies Nonfunctional Requirement Issue	NFRI5, NFRI7
Satisfies Non-functional Objective	INFRO5, INFRO7
Constrains	P1, P8
Satisfied by prototype feature	All prototype screens (Destination Selection, Route Selection, Navigation Instructions, Emergency)

NFR ID	**Nonfunctional Requirement 6**
NFR6	The UI of the system can be rearranged and resized (swap locations of the large buttons, increase/decrease text size).
Operationalized Functional Requirements	FR2, FR8
Satisfies Nonfunctional Requirement Issue	NFRI5, NFRI7
Satisfies Non-functionals Objective	INFRO5, INFRO7
Constrains	P1, P4, P8
Satisfied by prototype feature	Menu Configuration

NFR ID	**Nonfunctional Requirement 7**
NFR7	Each component of the system (navigation algorithm, building mapping system, obstacle detection, etc.) is modular, allowing for future updates and extensibility.
Operationalized Functional Requirements	FR1, FR2, FR9, FR10, FR7
Satisfies Nonfunctional Requirement Issue	NFRI8
Satisfies Non-functional Objective	INFRO8
Constrains	P3, P5, P7
Satisfied by prototype feature	N/A (internal architecture/implementation structure-not visible in UI prototype)

NFR ID	**Nonfunctional Requirement 7**
NFR8	App is built to be modular. Language, third party services for maps, sensors used for locating are interchangeable.
Operationalized Functional Requirements	All FRs (system-wide architectural requirement)
Satisfies Nonfunctional Requirement Issue	NFRI8
Satisfies Non-functional Objective	INFRO8
Constrains	P7

Satisfied by prototype feature	N/A (architectural framework)

4.2.3. Specifications

Figure 8 shows a KAOS model of the route computation goal.

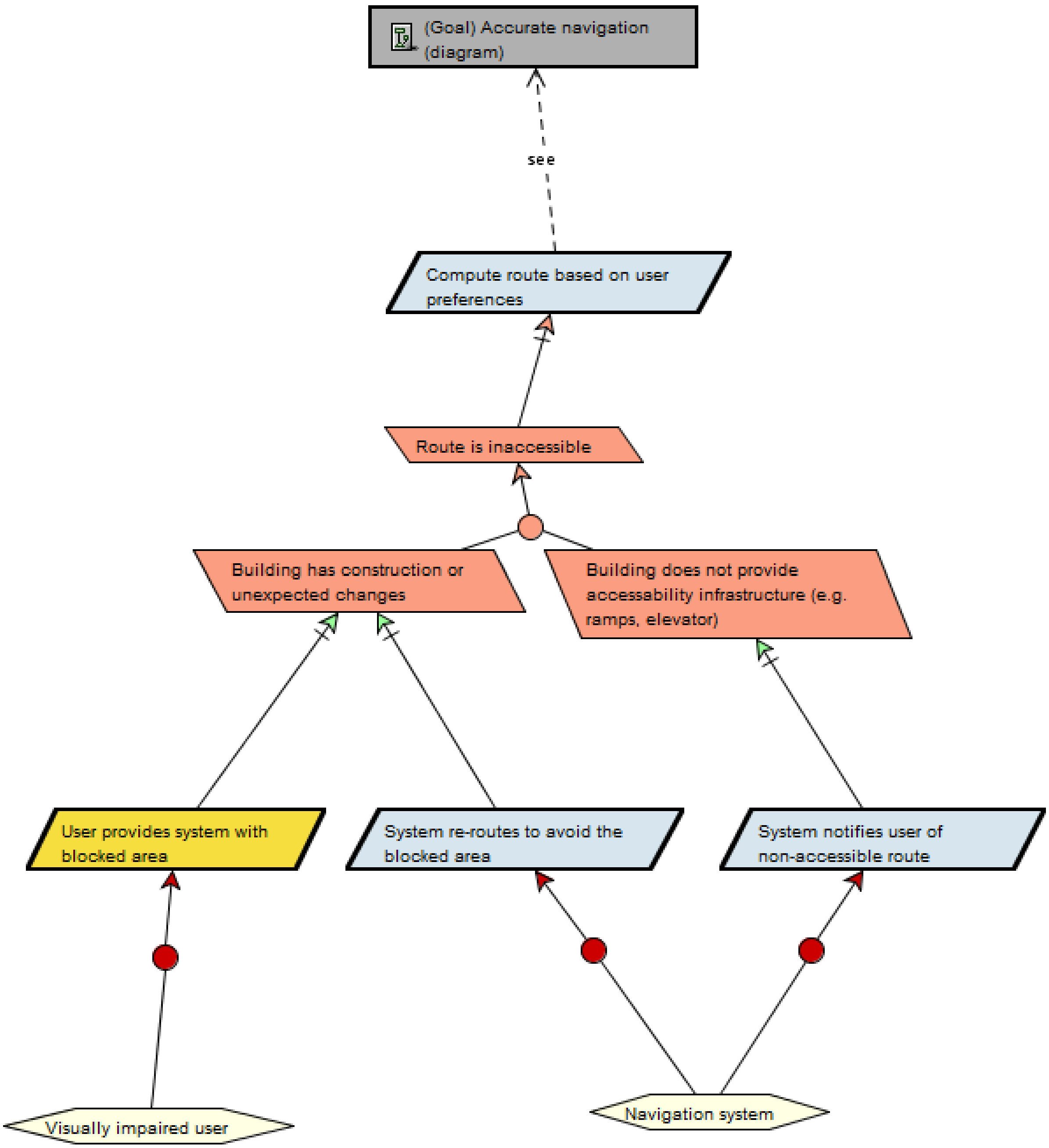

Figure 8. Requirement: Compute route based on user preferences

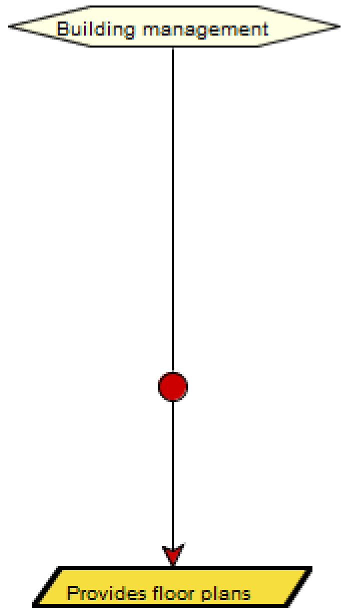

Figure 9. Responsibility: Building management

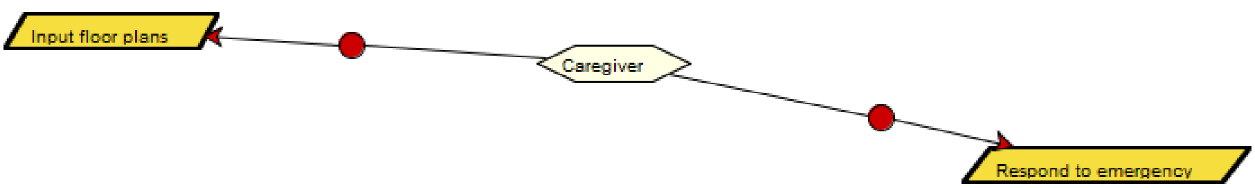

Figure 10. Responsibility: Caregiver

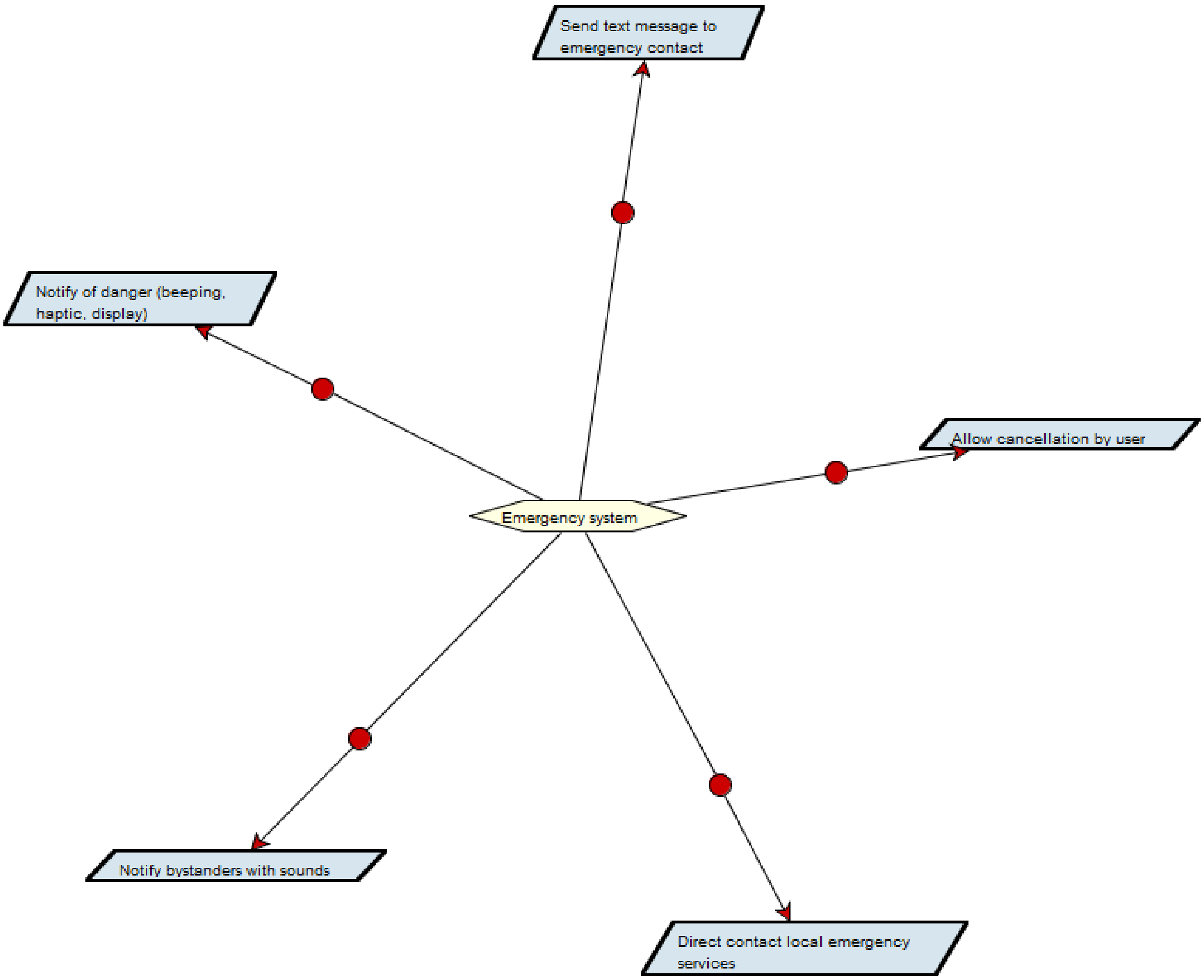

Figure 11. Responsibility: Emergency system

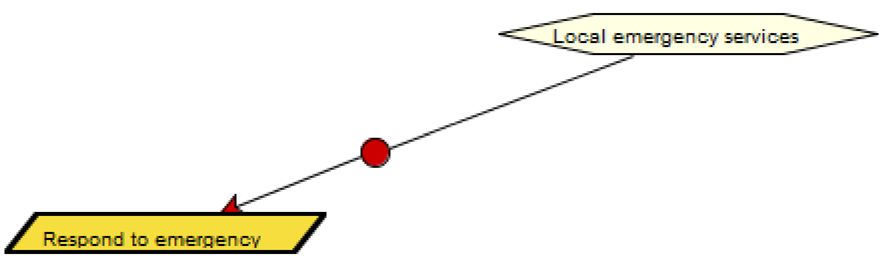

Figure 12. Responsibility: Local emergency services

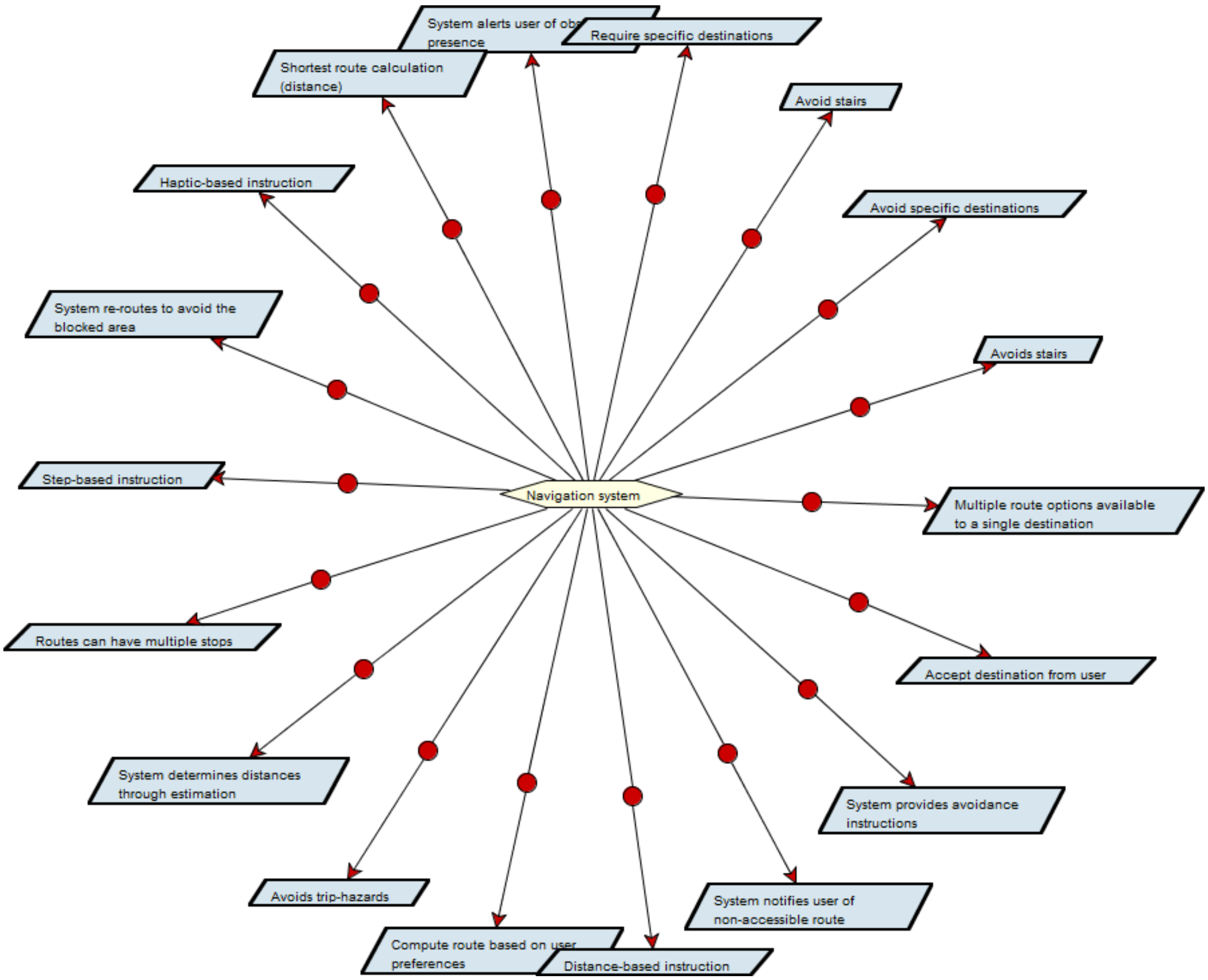

Figure 13. Responsibility: Navigation system

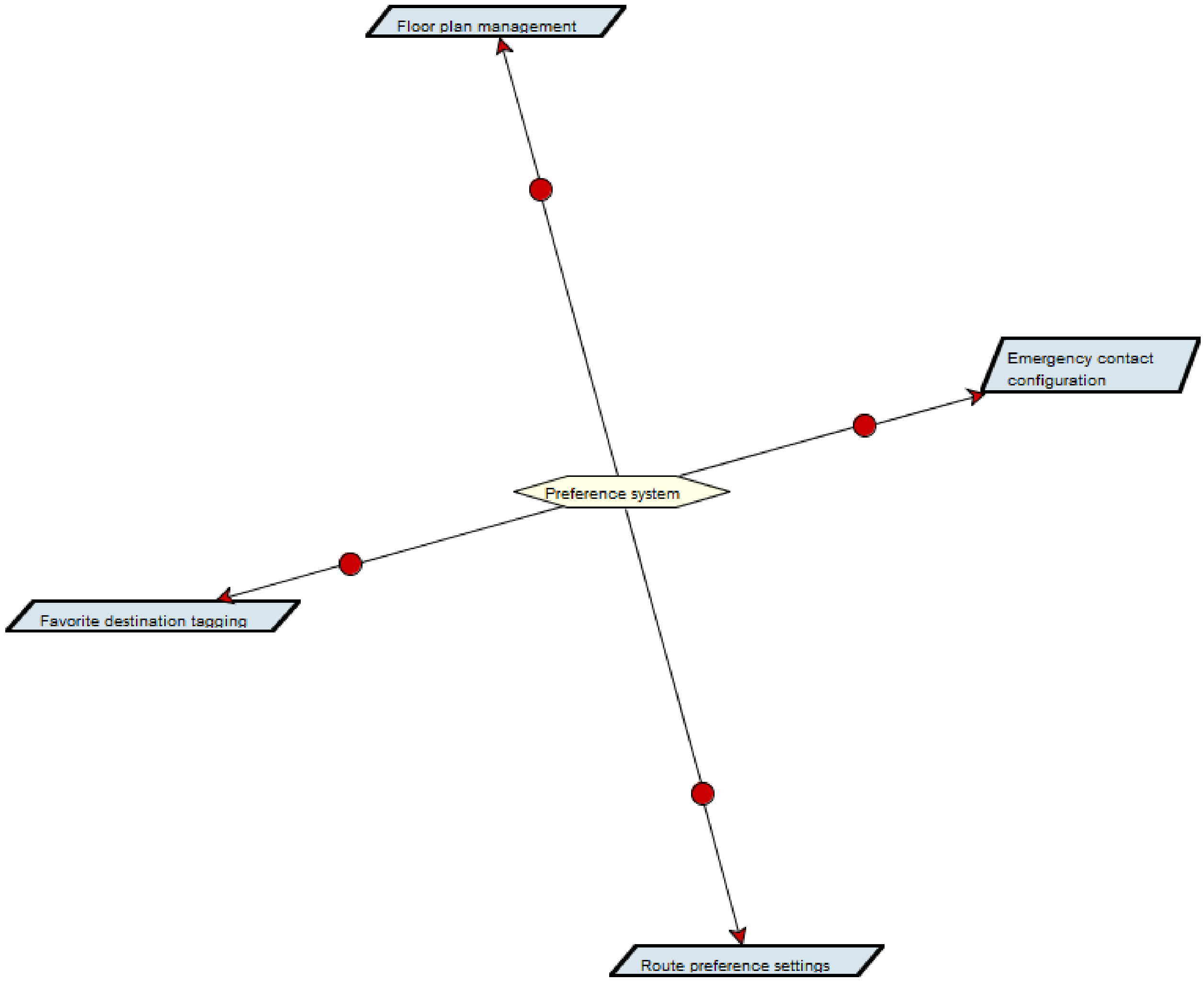

Figure 14. Responsibility: Preference system

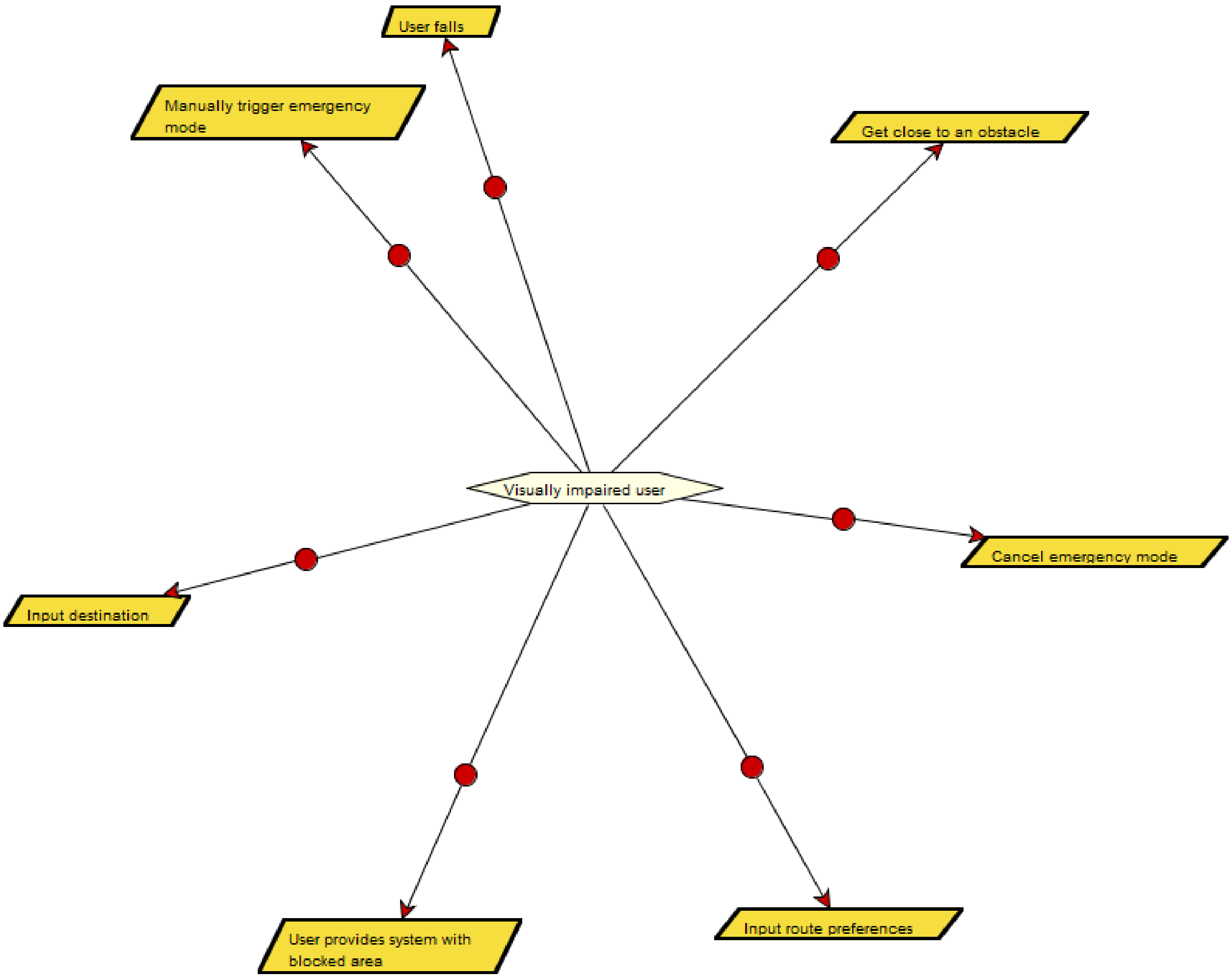

Figure 15. Responsibility: Visually impaired user

Functional Specification ID	**Functional Requirement**
FS1	When user inputs a destination using Voice Commands, the system identifies a destination from the audio input and computes a navigation route from the user's current location to the destination or informs the user of invalid destination.
Satisfies Functional Requirement	FR1
Satisfies Objectives	IFRO1, INFRO5
Satisfied by prototype feature	Destination Selection

Functional Specification ID	**Functional Requirement**
FS2	When user select a destination using the Accessible Touch Interface, the system computes a navigation route from user current location to that destination
Satisfies Functional Requirement	FR2

Satisfies Objectives	IFRO1, INFRO5
Satisfied by prototype feature	Destination Selection

Functional Specification ID	**Functional Requirement**
FS3	During navigation, the system continuously provides concise audio instructions in natural language that are configurable for: Volume level Speech rate (speed) Instruction frequency (how often between info) Travel Mode: Distance units (feet/meters) or step counting (10 steps)
Satisfies Functional Requirement	FR3
Satisfies Objectives	IFRO3, INFRO5
Satisfied by prototype feature	Navigation Instruction

Functional Specification ID	**Functional Requirement**
FS4	While navigating, the phone provides haptic feedback through distinct vibration patterns for approaching a waypoint, reaching a waypoint, and approaching an obstacle. Haptics are stronger for obstacles/dangers. Haptic patterns are configurable for: • Intensity (light/medium/strong) • Pattern customization • Enable/disable by feedback type
Satisfies Functional Requirement	FR4
Satisfies Objectives	IFRO3, INFRO5
Satisfied by prototype feature	Navigation Instruction

Functional Specification ID	**Functional Requirement**
FS5	Next suggestions for navigation are calculated based on favorite destinations or past travel history. They are presented to the user after reaching their destination through audible speech or a list in the UI.
Satisfies Functional Requirement	FR5
Satisfies Objectives	IFRO6
Satisfied by prototype feature	Destination Selection

Functional Specification ID	**Functional Requirement**
FS6	When the user begins navigation to a destination, the system enters step-by-step navigation mode and

	provides continuous audio instructions indicating current direction, distance to next action, and upcoming waypoints (turns, stairs, elevators). Instructions update in real-time as the user moves along the route until the destination is reached or navigation is cancelled. The system will provide instructions at every waypoint (turns, stairs, elevators, etc.) The system will provide periodic updates on distance/progress if time between waypoints is long.
Satisfies Functional Requirement	FR6
Satisfies Objectives	INFRO1, IFRO3, INFRO3
Satisfied by prototype feature	Navigation Instruction

Functional Specification ID	Functional Requirement
FS7	When the user approaches a static obstacle or stairs, the system provides audible and haptic warnings at least 10 seconds in advance with the obstacle type and suggested action.
Satisfies Functional Requirement	FR7
Satisfies Objectives	INFRO1, IFRO4
Satisfied by prototype feature	Navigation Instruction

Functional Specification ID	Functional Requirement
FS8	When the user or caregiver accesses the configuration menu, the system presents accessible settings for navigation preferences, audio controls, and haptic feedback options. Changes to settings are saved and immediately applied to the navigation experience.
Satisfies Functional Requirement	FR8
Satisfies Objectives	INFRO7, INFRO8
Satisfied by prototype feature	Configuration Menu

Functional Specification ID	Functional Requirement
FS9	When the user selects a destination, the system calculates multiple route options based on speed, distance, user-configured avoidance settings, and accessibility requirements. The system presents the top route options to the user with estimated travel time for selection.

Satisfies Functional Requirement	FR9
Satisfies Objectives	IFRO2
Satisfied by prototype feature	Route Computation

Functional Specification ID	**Functional Requirement**
FS10	When the system detects a fall using phone sensors, it prompts the user to confirm their safety. If the user does not respond or confirms an emergency, the system initiates emergency contact procedures.
Satisfies Functional Requirement	FR10
Satisfies Objectives	IFRO5
Satisfied by prototype feature	Emergency Procedure

Functional Specification ID	**Functional Requirement**
FS11	When an emergency is confirmed, the system automatically contacts emergency services with the user's location and sends alerts to pre-configured contacts.
Satisfies Functional Requirement	FRI5
Satisfies Objectives	IFRO5
Satisfied by prototype feature	Emergency Procedure

[5] Preliminary Prototype

The preliminary prototype demonstrates the core features of the Theia indoor navigation app through visual mockups and interaction flows.

Preliminary Prototype features:

Destination Selection:

- Voice command input interface
- Touch-based destination browser
- Recent and favorite destinations
- Search functionality

Route Selection

- Multiple route options display
- Route characteristics (time, distance, accessibility)
- Route comparison interface

Navigation Instruction

- Step-by-step guidance display
- Audio instruction visualization
- Haptic feedback indicators
- Current position and next action
- Obstacle and hazard warnings

Emergency Procedure

- SOS manual activation gesture
- Fall detection alert
- Emergency confirmation dialog
- Emergency mode interface

Menu Configuration

- Navigation preferences
- Audio settings
- Haptic feedback customization
- UI customization options
- Accessibility settings

Route Computation

- Route calculation visualization
- Loading indicators
- Alternative route generation

Prototype UI Mock-ups

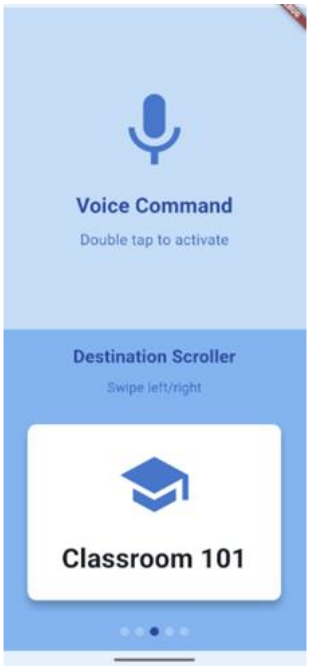

Figure 1: Home Screen

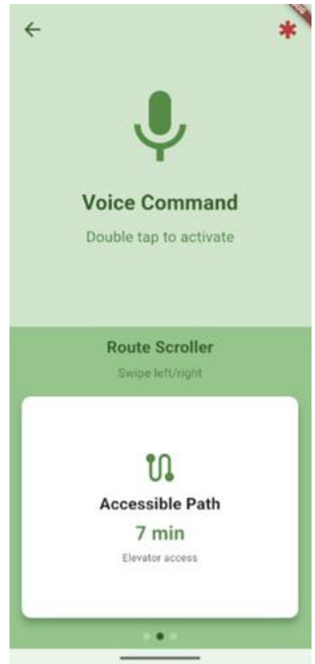

Figure 2: Route Selection

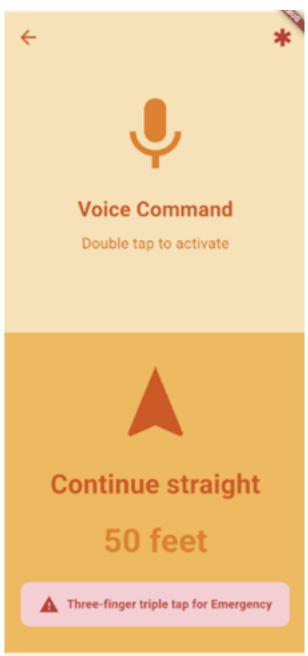

Figure 3: Navigation Screen

Figure 4: Emergency Alert Screen

[6] Alpha Prototype

For alpha prototype built on top of the UI from the preliminary prototype and add actual backend functionalities for:

- Text to speech and voice recognition
- Navigation instructions
- Destinations Selection
- Audio guidance
- Emergency Fall detection
- Emergency contacts configurations

[7] User Manual

The user manual is a separate document that contains all instructions and basic features of the Theia mobile app prototype.

[8] References

[1] Erickson, W., Lee, C., & von Schrader, S. (2012). 2010 Disability Status Report: United States. Ithaca, NY: Cornell University Employment and Disability Institute(EDI).
[2] Erickson, W., Lee, C., & von Schrader, S. (2012). 2011 Disability Status Report: United States. Ithaca, NY: Cornell University Employment and Disability Institute(EDI).
[3] L. Chung (2014). *CS/SE 6361 Advanced Requirement Engineering, Spring 2014, Project Phase 1: Requirements Elicitation: Initial Understanding.* [Online]. Available: [material url]

- *Project Management Plan Template (Wiegers, 2013).*
- *Requirements Review Checklist (Wiegers & Seilevel, 2013).*
- *GitHub Repository – Theia Project - https://github.com/rk3026/Theia.*