



TED UNIVERSITY

Department of Computer Engineering

CMPE 491 – Senior Design Project I

Project Specification Report

TEDU Guide

Project Website: <https://tedu-guide.vercel.app/>

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1.1 Description

TEDU Guide is an AI-powered intelligent campus navigation system designed to address a persistent challenge at TED University: the difficulty of efficiently locating rooms, offices, laboratories, and facilities within a complex, multi-floor campus environment. Traditional navigation aids—such as static floor plans and printed directories—are often inadequate for a dynamic campus where schedules change and facilities are frequently updated.

To provide a seamless navigation experience, the platform integrates three core technologies:

- **Indoor Positioning:** Utilizing the existing wireless infrastructure, the system employs **WiFi Fingerprinting** based on Received Signal Strength Indicator (RSSI) values. This allows for precise real-time location tracking indoors where GPS is typically unavailable.
- **Natural Language Processing (NLP):** An intuitive conversational interface allows users to interact with the system using natural queries such as *"Where is the nearest study room?"* or *"What is the fastest route to the cafeteria?"*, eliminating the need for complex hierarchical menus.
- **Interactive Visualization:** A dedicated mapping layer renders zoomable, annotated floor plans of campus buildings with dynamically highlighted routes and points of interest.

The platform will be delivered as a mobile-compatible web application, accessible via any device browser without requiring installation. The technical stack includes a **FastAPI (Python)** backend, a **PostGIS-enabled PostgreSQL** database for spatial data management, and a **React** frontend utilizing the **Leaflet.js** library. The NLP component is powered by **OpenAI's API** for advanced intent recognition and context-aware response generation.

1.2 Constraints

A set of real-world constraints shapes and limits the design and implementation of TEDU Guide. These constraints span economic, environmental, social, political, ethical, health and

safety, manufacturability, and sustainability dimensions as defined in engineering design frameworks.

Economic Constraints

The project is developed within the scope of an undergraduate senior design course, meaning there is no dedicated project budget. All infrastructure costs must be minimized through the use of open-source tools (React, Leaflet.js, FastAPI, PostgreSQL/PostGIS), free-tier cloud hosting services, and the university's existing WiFi hardware. Any reliance on paid third-party APIs — such as OpenAI — must be limited to low-volume usage within free or student-plan tiers. The absence of hardware procurement means the indoor positioning component must rely exclusively on TEDU's pre-existing WiFi access point network, without deploying additional beacons or sensors.

Environmental Constraints

Because TEDU Guide operates entirely as a software system running on existing infrastructure, its direct environmental footprint is negligible. However, the system must account for the physical environment: indoor WiFi signal propagation is subject to multipath interference, signal attenuation through walls and floors, and interference from other wireless devices. These environmental factors directly limit the achievable accuracy of indoor positioning to approximately 3–5 meters under realistic campus conditions. The system must also function reliably in high-density environments (e.g., during class breaks when many users may be active simultaneously) without degraded performance.

Social Constraints

The system must be accessible to a socially diverse user base that includes first-year students unfamiliar with technology, international exchange students, users with visual or physical disabilities, and campus visitors of varying ages and technical literacy. The interface must be intuitive enough to require no training or onboarding. Furthermore, the system must support accessibility for visually impaired users through a voice-only interaction mode, and for users

with mobility impairments by explicitly marking elevator-accessible, step-free routes in navigation instructions.

Political Constraints

As a system deployed within TED University's institutional environment, TEDU Guide must operate in compliance with the university's IT policies, data governance frameworks, and any applicable Turkish national data protection legislation, including the Law on Protection of Personal Data (KVKK — Law No. 6698). Any collection or processing of user location data must be conducted transparently and with user consent. The system must also not interfere with the existing university network infrastructure or create unauthorized traffic loads on the campus WiFi system.

Ethical Constraints

The system involves the continuous processing of user location data, which constitutes sensitive personal information. Ethical constraints require that: (1) location data is processed locally on the user's device where possible and is not persistently stored on remote servers without explicit, informed user consent; (2) users are clearly informed about what data is collected and for what purpose; (3) no user profiling or behavioral analysis is performed beyond what is necessary for navigation; and (4) the system does not create or reinforce discriminatory access patterns. Ethical dimensions are elaborated further in Section 1.3.

Health and Safety Constraints

The system must not pose any risk to users engaged in physical navigation. Specifically, navigation instructions presented on screen must be clear and unambiguous to prevent users from making sudden, dangerous movements (e.g., abrupt turns near stairwells). The optional haptic feedback feature — where the device vibrates once for a left turn and twice for a right turn — is designed to reduce screen dependence during navigation and mitigate the safety risk of distracted walking. The system must also clearly indicate hazardous or restricted areas where navigation should not be directed.

Manufacturability Constraints

As a purely software system, manufacturability constraints pertain to deployment and maintainability rather than physical production. The system architecture must be designed to allow administrative staff to easily update the campus location database (room assignments, office relocations, facility hours) through a dedicated admin interface, without requiring developer intervention. Floor plan data, which must be digitized from physical building blueprints, represents the highest-effort one-time setup task and constitutes a practical constraint on the system's initial scalability across all campus buildings.

Sustainability Constraints

The system must be maintainable and extensible beyond the duration of this senior design project. This requires that the codebase be well-documented, modular, and built on stable, long-term-supported frameworks. The WiFi fingerprinting model requires periodic recalibration as the campus WiFi infrastructure evolves (access point additions or relocations); the system architecture must accommodate this recalibration workflow without requiring a full system rebuild. Additionally, the campus information database schema must be designed to accommodate future data additions (new buildings, updated room assignments) with minimal structural changes.

1.2.1 Literature Review

The following literature directly informs the design and implementation decisions of TEDU Guide. Sources are organized by technical domain.

Bahl & Padmanabhan (2000) — RADAR System

The foundational work on WiFi-based indoor positioning. RADAR demonstrated that Received Signal Strength Indicator (RSSI) values from 802.11 access points can be used to determine user location with approximately 2–3 meter accuracy in controlled environments. TEDU Guide adopts the same fingerprinting principle: a site survey phase collects RSSI vectors at known reference points; at runtime, the user's observed RSSI vector is matched against this database using k-Nearest Neighbors (k-NN). Key limitation identified by RADAR: accuracy degrades significantly with multipath interference and environmental changes

(furniture movement, door states, crowd density). This directly motivates our system's stated 3–5 meter accuracy bound (NFR-02 / FR-02).

Reference: Bahl, P., & Padmanabhan, V. N. (2000). RADAR: An in-building RF-based user location and tracking system. *Proceedings of IEEE INFOCOM 2000*, 2, 775–784.

Liu et al. (2007) — Survey of Wireless Indoor Positioning

A comprehensive review comparing infrastructure-based (WiFi, Bluetooth, ultrasound, infrared) and infrastructure-free (inertial, vision) indoor positioning techniques. The survey establishes that WiFi fingerprinting offers the best trade-off between accuracy and deployment cost for environments with existing wireless infrastructure — precisely the constraint TEDU Guide operates under (Economic Constraint: no new hardware procurement). The survey also documents that k-NN and probabilistic (Bayesian) methods are the dominant approaches for fingerprinting-based localization, reinforcing our choice of k-NN (PR-03).

Reference: Liu, H., Darabi, H., Banerjee, P., & Liu, J. (2007). Survey of wireless indoor positioning techniques and systems. *IEEE Transactions on Systems, Man, and Cybernetics, Part C*, 37(6), 1067–1080.

Aggarwal & Chugh (2022) — Machine Learning for Indoor Positioning

A recent review covering advances in ML-based indoor positioning from 2010 to 2022, including deep learning approaches (CNNs, LSTMs, autoencoders) applied to RSSI fingerprinting. The paper demonstrates that while deep learning models achieve higher accuracy than k-NN in large-scale environments, k-NN remains competitive and significantly more interpretable and maintainable in constrained deployments. Given our sustainability constraint (the model must be recalibratable by future maintainers without a full system rebuild), k-NN is the appropriate baseline. The paper also highlights transfer learning as a promising direction for reducing recalibration effort when AP configurations change.

Reference: Aggarwal, P., & Chugh, N. (2022). Review of machine learning techniques for indoor positioning. *Journal of Location Based Services*, 16(4), 280–322.

OpenAI GPT-4 Technical Report (2024)

GPT-4 is the large language model underlying TEDU Guide's NLP component (PR-02). The technical report documents the model's strong performance on intent classification, entity extraction, and context-aware response generation — all capabilities required for parsing queries such as "Where is Professor Çapın's office?" or "What is the quickest elevator route to the cafeteria?". Critically, the report also documents hallucination risks, motivating our architectural decision to implement a validation layer (Algorithmic Accountability, Section 1.3): AI-generated responses are cross-checked against the structured campus database before being presented to users.

Reference: OpenAI. (2024). GPT-4 Technical Report. OpenAI.
<https://openai.com/research/gpt-4>

ACM Code of Ethics and Professional Conduct (2018)

Principle 1.6 ("Respect privacy") and Principle 2.5 ("Give comprehensive and thorough evaluations") directly shape TEDU Guide's data minimization design and the validation layer requirement respectively. Our privacy architecture (session-only location data, opt-in consent, fallback mode without location tracking) is derived from ACM 1.6 compliance.

Reference: ACM. (2018). ACM Code of Ethics and Professional Conduct.
<https://www.acm.org/code-of-ethics>

1.3 Professional and Ethical Issues

The development of TEDU Guide engages multiple dimensions of professional and ethical responsibility as articulated in established codes of ethics for computing and software engineering professionals.

Privacy and Data Minimization

The most significant ethical issue in TEDU Guide is the handling of user location data. Indoor positioning by definition requires knowledge of the user's physical whereabouts, which is sensitive personal information. In accordance with the ACM Code of Ethics and Professional Conduct (Principle 1.6 — "Respect privacy"), the system is designed around a principle of data minimization: only the data strictly necessary for delivering navigation assistance is collected, retained only for the duration of the active session, and never shared with third parties. Users are presented with a clear privacy notice upon first use and must provide explicit opt-in consent before any location data is processed. The system provides a functional — though less precise — mode of operation even if the user declines location tracking, allowing manual selection of their starting point.

Transparency and Informed Consent

The IEEE Code of Ethics obliges engineers to be honest and realistic in claims about systems and their capabilities. TEDU Guide must communicate clearly to users what the system can and cannot do: the positioning accuracy is bounded to approximately 3–5 meters, the campus database may not reflect very recent changes, and the NLP interface may occasionally misinterpret ambiguous queries. Error messages and fallback responses must be informative rather than misleading, and the system must acknowledge uncertainty where it exists rather than presenting erroneous information with false confidence.

Accessibility and Fairness

The IEEE Software Engineering Code of Ethics (Principle 3.12) requires software engineers to work to develop software that is accessible to users with disabilities. TEDU Guide directly addresses this by implementing a voice-only interaction mode for visually impaired users and by providing accessibility-aware routing (elevator and step-free path options) for users with mobility impairments. Failing to support these user groups would constitute a professional and ethical deficiency in a system intended to serve the entire university community.

Algorithmic Accountability

The NLP component, powered by a large language model, may produce responses that are incorrect, contextually inappropriate, or unexpected. In accordance with the ACM Code of Ethics (Principle 2.5 — "Give comprehensive and thorough evaluations of computer systems and their impacts"), the system must implement a validation layer to filter and verify AI-generated responses against the campus database before presenting them to users. The system must not blindly relay model output; instead, grounded responses backed by structured data must be prioritized. Edge cases where the model cannot produce a reliable response must trigger a graceful fallback.

Institutional Compliance and Professional Responsibility

As a system operating within TED University's infrastructure, the development team bears professional responsibility for complying with the university's IT acceptable use policies and

Turkish data protection law (KVKK). The team must ensure that the campus WiFi infrastructure is not accessed in any unauthorized manner during the fingerprinting data collection phase; all data collection must be conducted with formal approval from university IT administration. This aligns with the IEEE Code of Ethics obligation to "avoid injuring others, their property, reputation, or employment" and to "act consistently with the public interest."

2. Requirements

2.1 Functional Requirements

The following functional requirements define the behaviors that the TEDU Guide system must support. Each requirement is stated using the "shall" convention to indicate mandatory behavior.

FR-01 — Indoor Positioning

The system shall determine the user's real-time indoor location by collecting and analyzing WiFi RSSI (Received Signal Strength Indicator) signals from nearby campus access points using a pre-trained fingerprinting model.

FR-02 — Location Accuracy

The indoor positioning subsystem shall localize the user's position to within 3–5 meters under standard campus WiFi signal conditions in calibrated building areas.

FR-03 — Natural Language Query Processing

The system shall accept free-form natural language queries from users (submitted via text input or voice input) and parse the user's intent to return relevant campus information including room locations, office assignments, facility hours, and navigation routes.

FR-04 — Route Generation

The system shall compute and display the optimal indoor route between any two points on campus, accounting for floor transitions via staircases or elevators, and render the route as a highlighted path on the interactive floor plan.

FR-05 — Accessibility Routing

The system shall provide an accessibility-aware navigation mode that restricts route options to step-free paths and elevator corridors, activated when the user enables the accessibility option.

FR-06 — Interactive Floor Plan

The system shall render interactive, zoomable floor plan maps for each campus building, displaying rooms, corridors, staircases, elevators, and labeled points of interest.

FR-07 — Campus Information Database Query

The system shall maintain a structured database of campus locations, including room numbers, office assignments, faculty names, facility types, and operating hours, which is queried in response to user navigation and information requests.

FR-08 — Admin Interface

Authorized administrators shall be able to add, edit, and remove location entries, update room assignments, and modify facility operating hours through a secured administrative web interface without requiring code-level modifications.

FR-09 — Voice-Only Mode

The system shall support a voice-only interaction mode in which all navigation instructions and location information are delivered via synthesized audio output, enabling use by visually impaired users without requiring screen interaction.

FR-10 — Offline Capability

The system shall remain functional for a minimum of 30 seconds and up to 90 seconds of network disconnection, serving cached navigation data and the most recently loaded floor plan without requiring a network connection.

FR-11 — Haptic Navigation Feedback (Optional)

When operating on a mobile device, the system should provide haptic (vibration) feedback to indicate turn directions: one vibration pulse for a left turn, two vibration pulses for a right turn, allowing users to navigate without continuous screen interaction.

FR-12 — Guest Access

The system shall be accessible to campus visitors connecting via the university's guest WiFi network, without requiring authentication or university account credentials.

2.2 Non-Functional Requirements

NFR-01 — Response Time

The system shall respond to navigation and information queries within 2 seconds under normal network conditions and typical server load.

NFR-02 — Scalability

The system shall support concurrent usage by at least 100 simultaneous users without measurable degradation in response time or positioning accuracy.

NFR-03 — Availability

The system shall target 99% uptime during university operational hours (08:00–22:00 on weekdays).

NFR-04 — Usability

The interface shall be fully functional on both desktop and mobile web browsers without requiring any native application installation, and shall be operable by a first-time user without any prior training or instruction.

NFR-05 — Security

All communication between the client application and the backend server shall be encrypted via HTTPS/TLS. User location data shall not be persistently stored on the server beyond the active session without explicit user consent.

NFR-06 — Privacy

The system shall comply with applicable Turkish personal data protection legislation (KVKK — Law No. 6698) and shall implement data minimization principles, retaining only session-scoped location data unless the user explicitly opts in to extended data storage.

NFR-07 — Maintainability

The system codebase shall be organized into modular components with documented interfaces, enabling independent updates to the positioning model, NLP integration, floor plan data, and campus database without requiring full system redeployment.

NFR-08 — Portability

The system shall be deployable on standard cloud hosting platforms and shall not be dependent on proprietary infrastructure specific to TED University's internal systems.

2.3 Pseudo Requirements

PR-01 — Technology Stack

The frontend shall be implemented using React.js with the Leaflet.js library for interactive floor plan rendering. The backend API shall be implemented using Python with the FastAPI framework. Spatial location data shall be stored in a PostgreSQL database with the PostGIS extension.

PR-02 — AI/NLP Engine

The natural language understanding and intent recognition component shall be implemented using the OpenAI API (GPT-4 or equivalent) with prompt engineering techniques to constrain responses to campus-relevant information.

PR-03 — Positioning Algorithm

The indoor positioning component shall implement a WiFi fingerprinting algorithm using RSSI data collected from the campus wireless access point network, trained using a supervised machine learning model (k-Nearest Neighbors or equivalent).

PR-04 — Deployment Platform

The web application shall be deployed on a publicly accessible hosting platform (e.g., Vercel for the frontend, Render or Railway for the backend) with a custom domain linked to the project website.

3. References

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