# Indoor Navigator - Finding the right path to your goal indoors - A Pervasive Computing Project Report

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***Abstract*—Indoor navigation presents unique challenges that conventional Global Navigation Satellite Systems (GNSS)-based applications fail to address. This project explores the development of "Indoor Navigator", a smartphone-based indoor navigation solution designed for guiding users within the Luleå University of Technology (LTU) campus. The application leverages modern smartphones' built-in location services, combining navigation services and floor plans with pathfinding algorithms to facilitate seamless indoor wayfinding. The system was evaluated through real-world user testing involving six participants navigating to different rooms within the university. Results demonstrated a high success rate, with 17 out of 18 tests completed successfully. Users rated the application positively in terms of usefulness (8.33/10 personally, 8.5/10 in general) and intuitiveness (8.33/10). Despite minor challenges related to positioning accuracy and map readability, participants reported improved confidence in navigation when using the application. These findings highlight the system's potential to assist new students and visitors in unfamiliar indoor environments while identifying areas for future refinements, such as improved positioning precision and expanded building coverage.**

***Index Terms*—Scientific writing, Pervasive Computing, smartphone positioning, indoor environment**

## I. Introduction

Everyday navigational applications like Google Maps help us with finding the shortest path to our destination without requiring any prior knowledge about our surroundings. These applications make everyday life easier, however they often do not extend to the area of indoor-navigation, where data is less publicly available and the environment poses challenges for positioning approaches focussing on Global Navigation Satellite Systems (GNSS). In this project report we present our prototype for **Indoor Navigator**, a mobile phone application for indoor navigation of rooms at Luleå campus of the Luleå tekniska universitet (LTU). Our prototype uses in-built location services of modern smartphones for indoor positioning with the help of inertial navigation (IN) approaches to determine crucial information like floor changes inside of buildings. Using floor plans and modern pathfinding algorithms we augmented the navigation system to support navigation through the interior layout of buildings.

In Section II we will discuss the scientific background around the field of indoor positioning and indoor navigation and related research that helped us in developing our prototype. Section III covers the utilized software and hardware, while Section IV presents the underlying architecture of the developed prototype. Next we present details about the design and actual implementation of our prototype in Section V. The functionality of the application is assessed via user tests in Section VI with results being discussed in Section VII. Finally the results of the testing and the implications as well as further possible research are discussed in Section VIII with concluding remarks in Section IX.

## II. Background and related research

The field of navigation can be broadly categorized into outdoor and indoor navigation. While outdoor navigation utilizes GNSS like GPS for accurate positioning data, indoor environments are challenged in this regard as the surrounding structures obstruct the signal coming from satellites thereby weakening its signal strength. Additionally doors, walls or furniture can cause multipath effects while other electronic devices indoors might cause interferences with the signal making GNSS information less reliable indoors.

Instead of solely relying on GNSS different indoor navigation topologies have emerged in concurrent literature to substitute or supplement satellite information like GPS. According to [1] one can differentiate between three classes of indoor navigation:

1) Designated technologies based on pre-deployed signal transmission infrastructure
2) Technologies based on so-called "signals-of-opportunity" (SoP)
3) Technologies not based on signals

The second class of using SoP seems especially prevalent in real-life use-cases as data signals of existing infrastructures like WiFi routers can be cost-effectively utilized.

Another important distinction in indoor navigation systems is the differentiation between absolute and relative positioning approaches [2]. While absolute positioning refers to determining a user's location with fixed coordinates relative to a global reference system, such as GPS, relative positioning estimates location based on nearby reference points and the relative position of objects to those reference points. Hybrid solutions exists that try to combine absolute and relative positioning approaches.

According to Google[1] the in-built android location service combines different inputs to estimate a location in indoor environments where GPS signals aren't available or accurate. These inputs include GPS, mobile network and WiFi signals as well as sensor data from the Inertial Measurement Unit (IMU) inside of modern smartphones.

This hybrid solution employs different localization approaches depending on the processed input. Mobile network signals can be leveraged by cell-based positioning approaches that roughly estimate the current location of a device based on its nearest signal source. WiFi signals as SoP can be applied in both lateration and fingerprinting approaches. Lateration estimates a device's location by measuring the distance to at least three different WiFi access points with known positions, using signal properties such as time-of-flight or received signal strength. In contrast, location fingerprinting relies on a database of pre-recorded WiFi signal strength patterns, comparing real-time measurements from surrounding access points to this database to determine the most likely location. Sensor data from the IMU of modern smartphones includes information from the accelerometer, gyroscope, magnetometer and barometer that can be interpreted using the relative positioning approach of Inertial Navigation (IN), where the trajectory of a user is estimated via velocity, acceleration and orientation measurements from these sensors. Since such estimations suffer from integrations drifts which can lead to a significant error margin over time, Dead Reckoning (DR) combines this relative positioning data with regular updates and information from other sources such as the above mentioned approaches for absolute positioning. [2]

## III. Materials

### A. Software

The indoor navigation application was developed using Android Studio, which provided a robust and integrated development environment for designing, coding, and testing. This choice facilitated efficient software development and deployment on Android devices, ensuring compatibility with modern smartphones and smartwatches. Android Studio supported a rapid development workflow, with extensive use of the emulator and debugging tools enabling quick iteration and problem-solving during implementation.

For data collection and mapping, the MAP LTU website was utilized, with API calls made to retrieve information about room locations and floor levels. While this approach provided valuable real-time data, it also introduced a reliance on an active internet connection, a limitation that was initially intended to be avoided during project planning. Additionally, OpenStreetMap was integrated to obtain a base map of the area, and Mapsforge was used for efficient rendering of vector-based maps. Mapsforge was particularly valuable for its ability to map longitude and latitude coordinates onto the screen, a feature that significantly reduced the development effort required to implement similar functionality independently.

The application relies on the ***Android Fused Location Provider*** to provide real-time position updates, which necessitates an active network connection. This dependence on network connectivity posed challenges in environments with weak or unreliable signals, affecting real-time navigation accuracy. Although alternative approaches exist, such as those discussed in the previous section, they were beyond the scope of this project.

### B. Hardware

Our application was designed to run on Android 14+ smartphones, with primary testing conducted on Samsung Galaxy S24 and Google Pixel devices. These models provided a diverse testing environment, ensuring compatibility across different hardware configurations and performance levels.

In addition to smartphones, Pixel 2+ smartwatches were incorporated as an experimental feature. The watches displayed the same navigation data as the smartphone application, offering an alternative, hands-free method of accessing navigation instructions. While this feature was not a primary focus, it served as a basis for exploring potential extensions of the system and assessing the viability of smartwatch-based navigation assistance. Future iterations could expand on this functionality by incorporating haptic feedback or voice guidance for improved usability.

Augmented reality (AR) features were initially considered for integration using a Meta Quest Pro headset. The original concept involved overlaying AR navigation lines leading to the user's destination to provide a more immersive navigation experience. However, after evaluating the feasibility and practicality of AR for indoor navigation, it was determined that the integration would require a significant time investment without offering substantial benefits to real-world users. Additionally, the hardware constraints and user experience challenges associated with wearing a VR headset for indoor navigation made this approach impractical. As a result, this aspect of the project was abandoned in favor of more immediately impactful features.

[2]

[1]https://policies.google.com/technologies/location-data (last accessed 24.02.2025)

[2]Sources for pictures of: VR-Headset, Smartphone, Smartwatch

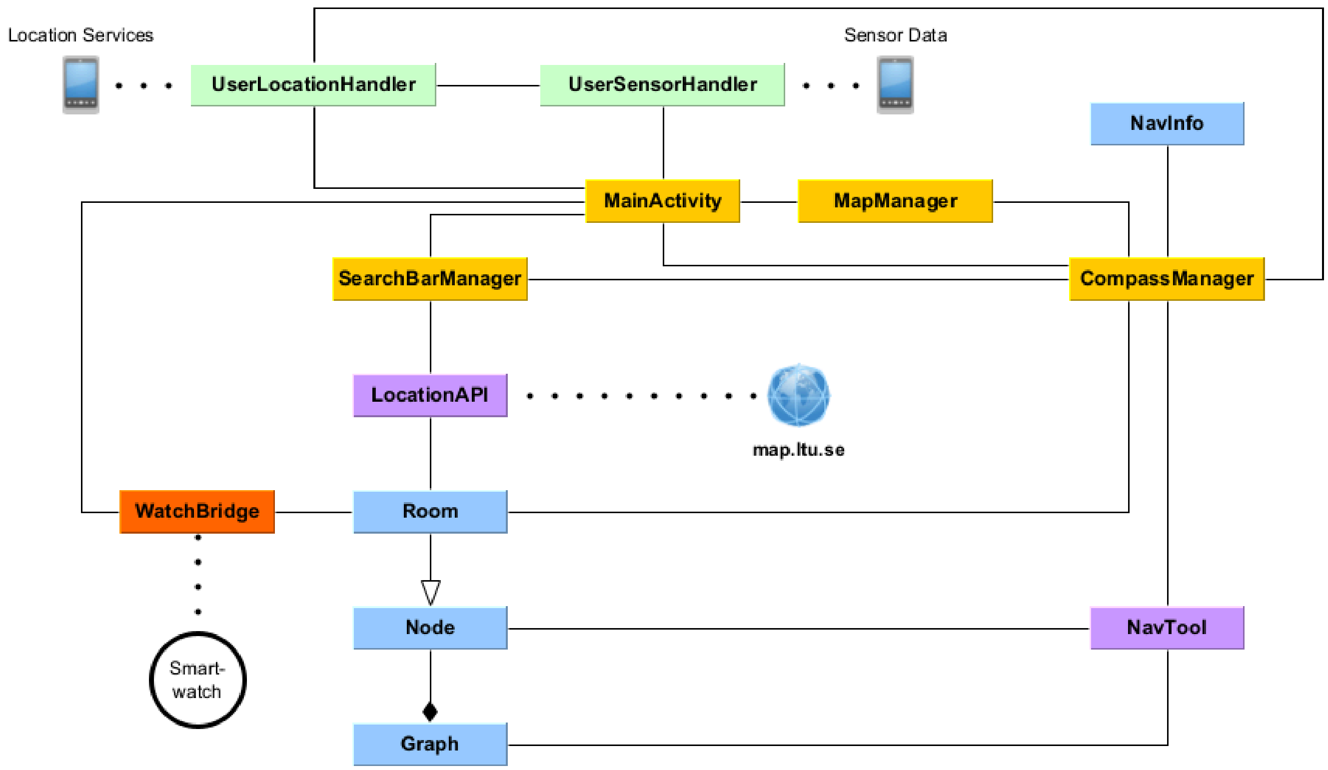


Fig. 1: Diagram of basic application architechture.

## IV. Application architecture

The general architecture of the **Indoor Navigator** application is made up of different modules that interact with each other and are responsible for specific purposes and contexts. Fig. 1 illustrates the basic architecture of the project.

The four central components of the application are *MainActivity*, *MapManager*, *CompassManager* and *SearchBarManager*.

- *MainActivity* as the central component initializes the application and other components and deals with issues like getting the user permissions of required system services like the location service.
- The *CompassManager* is responsible for managing the CompassView and it also contains a sizeable amount of the logic what happens when new location data is collected through its connection the the *UserLocationHandler*.
- The *MapManager* deals with the MapView inside of the compass that can be used for more detailed navigation information.
- Meanwhile the *SearchBarManager* handles the search functionality of searching for a room to which the navigation should lead the user. Through its connection with the *LocationAPI* this module handles and retrieves the location data from the remote map.ltu.se server.

The *LocationAPI* and *NavTool* components provide additional logic that is used by the central modules for their purposes.

- *LocationAPI* requests and caches location data about rooms that the user is looking for via the *SearchBarManager* and communicates with the map.ltu.se servers.
- The *NavTool* calculates the pathing from the current position to the target position using the *Graph* structure and makes this path accessible to *CompassManager*.

*UserLocationHandler* and *UserSensorHandler* deal with accessing and interpreting the location and sensor data from the smartphone on which the application is running. They also make this information accessible to the *CompassManager*.

*Room*, *Node*, *Graph* and *NavInfo* are structural classes that are used by the other components to store relevant information like the location of a room or construct graphs with nodes for the pathfinding algorithm in *NavTool*. The *NavInfo* class is used by the CompassManager to store information about current metrics of the application like the current location or heading that is displayed in different contexts throughout the application interface.

The *WatchBridge* component handles the connection and syncing of the application running on a phone and a smartwatch simultanously, so that the smartwatch displays the correct CompassView and MapView for the room the user is trying to navigate to via their smartphone.

## V. Application design and implementation

The primary objective of the app's design was to develop an indoor navigation tool for the LTU campus, enabling precise guidance through hallways and across different floors. To achieve this, the development process followed an iterative approach, with each iteration introducing additional layers of complexity to enhance both traversal accuracy and overall functionality.

*Initial Iteration: User Detection*

The first development phase served as a proof of concept, focusing on basic functionality. A compass-based system was implemented to measure the distance and bearing between the user and the designated destination. This iteration primarily assessed the feasibility of leveraging the device's built-in location services. Accuracy was a key consideration—if the system exhibited errors exceeding five meters, alternative methods for determining user coordinates would have been necessary. As outlined in Section IV, the hardware's location accuracy was deemed sufficient for the intended application. Additionally, initial testing involved using the compass and bearing data to locate predefined rooms in the A Hus building. Although the compass alone did not offer an ideal solution, it provided a foundation for further refinements, confirming the project's viability.

*Second Iteration: Destination Detection and Data Caching*

Building upon the user localization framework, the second iteration aimed to automate destination detection. While the first iteration established the app's theoretical potential, it lacked a structured approach for retrieving target locations. Efforts to obtain a comprehensive list of room numbers and corresponding geographic coordinates from official sources were unsuccessful. However, a viable alternative was identified—the LTU campus map website. By integrating this data, the application enabled users with internet access to retrieve geographic coordinates dynamically, with the added capability of caching this information for offline use. Additionally, this iteration introduced a visual map component, complementing the compass functionality and enhancing the user experience.

*Third Iteration: Floor Detection*

With both user and destination localization in place, the next step involved addressing floor detection, a critical challenge in indoor navigation. Various methodologies exist for floor determination, though some require external infrastructure or additional sensors, which would contradict the project's goal of accessibility. The development team prioritized utilizing in-built smartphone sensors, testing two potential solutions: the accelerometer and the barometer. The accelerometer, which measures vertical movement, proved unreliable due to its sensitivity—minor device movements could falsely indicate floor transitions. The barometer, measuring atmospheric pressure, demonstrated greater reliability. Once calibrated, pressure differentials were used to detect changes in altitude. However, factors such as temperature fluctuations and ventilation introduced variability, necessitating an initial user calibration process. A reference pressure difference of 0.32 hectopascals was adopted to infer floor transitions. While effective under controlled conditions, this approach remains subject to limitations, as pressure differentials may vary across time and location. A more robust implementation would involve leveraging publicly available atmospheric pressure data to dynamically adjust the threshold values.

*Final Iteration: Pathfinding and Prototype Completion*

The concluding development phase focused on optimizing route planning. Until this point, the navigation system relied solely on the compass method from the first iteration, which provided directional guidance but did not account for hallway layouts or optimal routing. To address this, a node-based navigation system was implemented, utilizing Dijkstra's algorithm to compute the shortest path between the user's current position and the destination. Initial tests yielded promising results, significantly improving the efficiency of navigation. In parallel, there was the implementation to enhance the UI alongside adding functionality of pairing a smartwatch with the app. The graphical representation of the navigation environment was enhanced by integrating vector-based maps of the A Hus building. Due to the limited availability of digital floor plans, testing was primarily conducted on the second floor. ***The rationale behind this decision is detailed in the subsequent section.*** The smartwatch on the other hand was simple to implement as it uses the already made UI and logical functionality of the app to display the updated UI to it.

## VI. Experimental Testing

### A. Tested features

User feedback is very important, especially for mobile development, as it provides a way to assess the effectiveness of a solution, and how it matches with user needs. In its current state, the **Indoor Navigator** application provides several features that can be tested in two different contexts:

Anywhere on the campus:

- User is able to enter its destination.
- Destination information is retrieved from *LTU* Map database.
- Destination information is stored in cache and available in the research history.
- Direction to the north is displayed on the compass (matching user rotation movements).
- Bird's-eye direction to the user destination is displayed on the compass.
- Bird's-eye distance to the user destination is displayed on the compass.
- User location is updated at least every 30 seconds, and the direction and distance to the destination is updated accordingly.
- User is prompted for the floor number when the navigation begins.
- Floor number is automatically updated when the user altitude changes.

- User location and destination is displayed on the map (accessible by *double tapping* the compass).
- The compass is also displayed (with realtime synchronization) on user wearable device (smartwatch).

In the A building:

- Detailed map of the building is displayed (instead of the regular map that lacks indoor mapping).
- The shortest path to the room is displayed on the map.
- Direction to the nearest node on the path is displayed on the compass

### *B. Design of experiment*

Randomly selected students are asked by an experimenter to go to 3 rooms in the A building (randomly selected in a list of 10 rooms) starting from one of the entrance of the A building. A smartphone with the application (and a smartwatch if available) is provided to the students without any indication. The experimenter follows the students. The experiment stops for each target location when the students have reached the destination (and acknowledged that they have arrived), or when they tell the experimenter that they are unable to reach the intended location. The students are then asked to answer a few question and provide their feedback on the application.

A set of quantitative data is gathered during the experiment:

- The number of occurrences of a successfully navigation (destination reached with the students acknowledging that they have reached the destination).
- The number of occurrences of failed navigation (the application is not useful or doesn't provide the student with correct information which leads to the students being unable to reach their destination in reasonable time, or give up during navigation)
- The number of application crash during navigation

The questions are aimed to gather qualitative data on the experiment:

- The usefulness of the application for the students (for them/in general)
- Students ability (according to them) to navigate in the building with and without the application
- Students likeliness to use the application if available to them

## VII. Results

Six different students volunteered to test the navigation application, for a total of 18 tests (as each student was asked to go to three different locations).

Qualitative feedbacks collected during the tests reported problems with the positioning accuracy, or map readability. However, none of these problem prevented them from reaching the room they were asked to go.

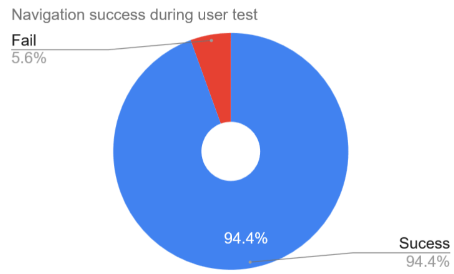


Fig. 2: Success and failure rate over all 18 conducted tests

As can be seen in Fig. 2, of the 18 tests, only one was considered inconclusive (the student wasn't able to find the room when they reached the location). The other 17 tests revealed that the students were able to use the application to locate a room, follow the path and reach the target location. No application crash or malfunction were noticed during any of the tests.

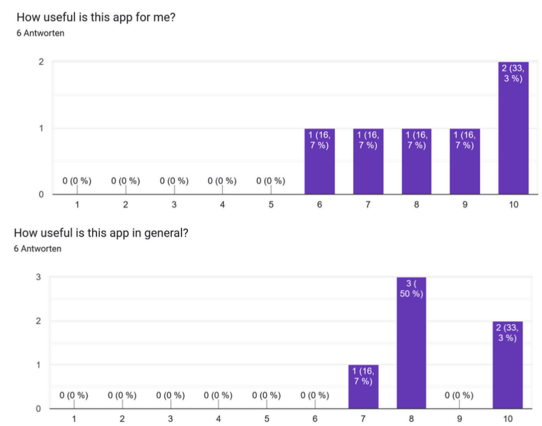


Fig. 3: Distribution of users perceived individual and general usefulness of the application on a 1-10 scale

User feedback on the application's usefulness is summarized in Fig. 3. Participants rated the app's usefulness on a 1-10 scale both for personal use and in a general sense. The average personal usefulness rating was 8.33, while the perceived general usefulness was slightly higher at 8.5. These results suggest that users found the app to be highly beneficial, both individually and as a tool that could assist others.

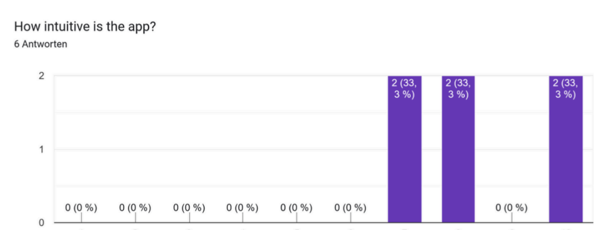


Fig. 4: Distribution of users perceived intuitiveness of the application on a 1-10 scale

As shown in Fig. 4, participants generally found the application intuitive to use, with an average intuitiveness rating of 8.33 out of 10. This indicates that the navigation interface and overall user experience were designed in a way that felt natural and easy to understand for most users.

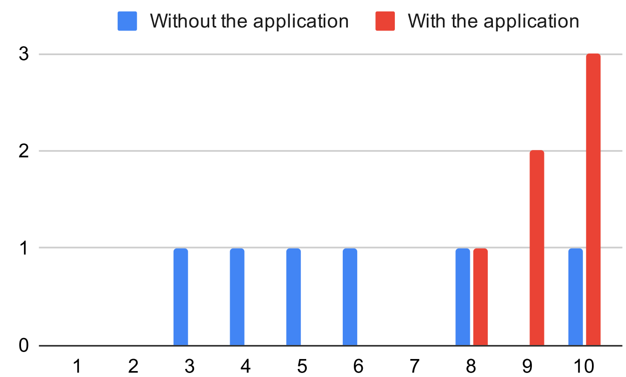


Fig. 5: Distribution of user self-evaluated ability to navigate in the university with and without the application on a 1-10 scale

Fig. 5 highlights a key benefit of the application: users felt significantly more confident navigating the university when using the app compared to navigating without it. On average, participants rated their navigation ability with the app approximately 30% higher than without it.

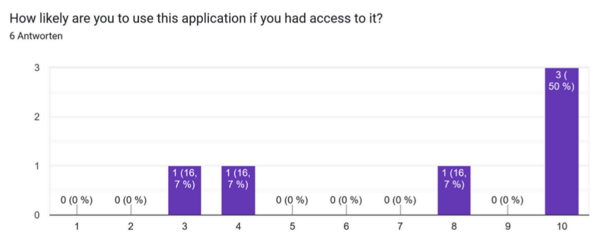


Fig. 6: Distribution of how likely users would be to use the application on a 1-10 scale

User willingness to adopt the application is depicted in Fig. 6. The responses varied, with four out of six participants expressing a high likelihood of using the app regularly, while two participants rated their likelihood lower, at 3 and 4 out of 10. Despite this variation, the average adoption likelihood was 7.5 out of 10, indicating a generally positive reception.

## VIII. Discussion

It should be noted that the students that agreed to test the application were mainly exchange students. We can make the hypothesis that exchange students have less knowledge on the buildings than the average LTU student, which makes these tests interesting.

Regarding the failed navigation in one case of the test runs, it was investigated after the fact that this failure was most likely due to missing room identification of the destination because the destination room seems to have been a toilet without such identification, further indicating the reliability of our prototype.

The main problems of qualitative nature during tested related to accuracy and the consistency of the compass directions. These problems can be mainly attributed either to inaccuracies of the current positioning system implemented and some technical faults in our application where previous waypoints on the way to the final destination were not appropriately deleted from the pathfinding because the user was not measured as close enough to the waypoint for the passing of it to register. This problem can most likely be easily solved. However the general inaccuracies and sometimes inconsistent positioning are dependant on more general improvements being made to the positioning system itself.

When it comes to adoption our limited testing shows that not all users would be likely to adopt the application. This might be due to the fact that once users already know how to get to their rooms the usefulness of the application decreases. As such our application seems most relevant for new students at university that do not yet know how to get to their destinations and might get help through our application.

The very limited testing scope and amount of participants can be improved upon in further iterations but even with minimal testing we could show that the prototype itself does what it should and guides users successfully to their required rooms with minimal effort and problems. Future studies should nonetheless expand testing and include a more diverse user sample to assess usability across different user groups.

### A. *Future Improvements*

While our prototype successfully demonstrates indoor navigation within Building A of the LTU campus in Luleå, several areas of improvement remain for future development.

One key enhancement would be expanding the system to support navigation in additional buildings and across more floors. Currently, the generation of pathfinding nodes from floor plans is a manual process; automating this step would significantly streamline the inclusion of new buildings into the system.

Similarly, the mapping of indoor floor plans to underlying open map data was performed manually in our prototype. Future iterations could focus on automating this process, facilitating easier integration of additional buildings while reducing the required manual effort.

Another area of potential improvement is the detection of floor changes using barometric pressure data. At present, the system relies on a fixed threshold to determine floor transitions, which may be influenced by environmental factors. By incorporating publicly available atmospheric pressure data, the application could dynamically adjust threshold values, improving the reliability and accuracy of floor detection.

Finally, the initial concept for our application included support for augmented reality (AR) glasses to enhance navigation. Due to time constraints, this feature was not implemented in the current prototype. Future work could focus on integrating AR glasses, providing a more intuitive and immersive navigation experience for users.

## IX. Conclusion

The Indoor Navigator project successfully demonstrated the feasibility of smartphone-based indoor navigation within the LTU campus. By integrating modern smartphones' built-in location services, combining navigation services and floor plans with pathfinding algorithms, the application provided users with an intuitive and effective solution for indoor wayfinding. User testing confirmed the system's reliability, with a strong success rate and favorable feedback regarding its usability and usefulness. While the application proved valuable for individuals unfamiliar with the university's layout, the study also revealed areas requiring improvement, particularly in positioning accuracy and floor detection mechanisms.

Future iterations should focus on refining the positioning system by incorporating methods like WiFi fingerprinting to enhance accuracy and expanding the pathfinding system to cover more buildings and complex indoor layouts. Enhancing floor detection by dynamically adjusting barometric thresholds using atmospheric pressure data could improve reliability. Automating the mapping of indoor floor plans to open map data would also simplify scaling the system. Additionally, integrating augmented reality (AR) glasses, as originally envisioned, could provide a more intuitive navigation experience by overlaying directional cues in real time.

Overall, this project lays a solid foundation for future advancements in indoor navigation, demonstrating the practical potential of pervasive computing in real-world applications. By addressing existing limitations and incorporating emerging technologies, the system could evolve into a widely applicable solution for various indoor environments, benefiting students, visitors, and professionals in complex buildings such as universities.

## Acknowledgements

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