DEVELOPMENT OF AN ACCESSIBLE AUGMENTED REALITY APPLICATION TO ENHANCE INDOOR NAVIGATION: A CASE OF HIGHER LEARNING INSTITUTIONS

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A Project Report Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Embedded and Mobile Systems of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

This study focused on developing an accessible Augmented Reality (AR) application to enhance indoor navigation, using a case study of learning institutions. A case of The Nelson Mandela African Institution of Science and Technology and Baden-Wuerttemberg Cooperative State University institutions were selected for this study. The project's objectives included gathering requirements for the development and understanding of the challenges faced by students, staff, and visitors who can be visually or non-visually impaired while navigating indoors in unfamiliar buildings. The project's significance lies in its potential to enhance indoor mobility, and accessibility, save time, and foster innovation in education technology. The application aims to create a more inclusive learning environment by improving indoor navigation. Primary data were collected through interviews and focus group discussions, creating a foundation requirement for developing the application. The study used Scrum Agile methodology to develop the application and web portal from the collected user requirements. The application was designed to run on smartphones and further, a web-based portal was designed for staff to update their visitor availability status. Development tools such as Unity, Microsoft Visual Studio, PHP, Python, and APIs were used. This study highlights the challenge of indoor navigation in higher learning institutions and the limited effectiveness of current solutions, especially for people with disabilities particularly the visually impaired. Leveraging AR technology, known for enhancing real-world perception by overlaying virtual content on top of users' real-world views, a user-friendly and accessible indoor navigation application was developed. 80% of the results demonstrated the effectiveness and usability of the application, with positive feedback from users highlighting its potential to transform the indoor navigation experience. In conclusion, the study underscores the need for further research to enhance indoor navigation, localization, and accessibility for a diverse range of users and use cases.

DECLARATION

I, Frank Samson, do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this project report is my original work and that it has neither been submitted nor is concurrently submitted for a degree award in any other institution.

16.08.2024

Frank Samson — Date

The declaration is hereby confirmed by:

16.08.2024

Dr. Mussa Dida Ally — Date

16.08.2024

Dr. Judith Leo — Date

16.08.2024

Prof. Sabine Mobs — Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology, a project report titled "*Development of an accessible augmented reality application to enhance indoor navigation in Higher learning institutions: A Case of Higher Learning Institutions"* in partial fulfillment of the requirements for the degree of Master of Science in Embedded and Mobile Systems, Mobile Systems specialty of the Nelson Mandela African Institution of Science and Technology.

16.08.2024

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DEDICATION

This work is devoted to God, my creator, and a wellspring of inspiration, understanding, and wisdom. I also dedicate it to my mother, siblings, and cherished friends, in recognition of all they have contributed.

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LIST OF ABBREVIATIONS AND SYMBOLS

SSID	Service Set Identifier
DHBW	Duale Hochschule Baden-Württemberg
NM-AIST	Nelson Mandela African Institution of Science and Technology
2D	Two-Dimensional
3D	Three-Dimensional
AR	Augmented Reality
RFID	Radio-Frequency Identification
NFC	Near Field Communication
WiFi	Wireless Fidelity
GPS	Global Positioning System
QR	Quick Response (Code)
LiDAR	Light Detection and Ranging
RF	Radio Frequency
SDLC	Software Development Life Cycle
VR	Virtual Reality
HTML	Hypertext Markup Language
CSS	Cascading Style Sheets
PHP	Hypertext Preprocessor
JS	JavaScript
JSON	JavaScript Object Notation
API	Application Programming Interface
RSSI	Received Signal Strength Indicator
C-GAN	Conditional Generative Adversarial Network
MySQL	My Structured Query Language
RF	Random Forest
KNN	K-Nearest Neighbors
MAE	Mean Absolute Error
MSE	Mean Squared Error
RMSE	Root Mean Square Error

DFD	Data Flow Diagram
IBM	International Business Machines Corporation
SLAM	Simultaneous Localization and Mapping
AINS	Augmented reality Indoor Navigation System
LISBE	Life Sciences and Bio-Engineering
BUSH	Business Studies and Humanities
MEWES	Materials, Energy, Water, and Environmental Sciences
COCSE	Computational and Communication Sciences and Engineering

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

A higher learning institution is defined as a college, university, or other similar establishment that provides postsecondary level academic instruction leading to an associate's degree or higher (Cornell Law School, 2023). Higher learning institutions serve as innovation centers, addressing societal challenges by generating research-based solutions. They are central to advancing knowledge and creating remedies tailored to contemporary issues (Shava *et al.,* 2023). The advancement of technology worldwide has brought about automation and digitization of different activities within institutions. However, there are still several activities that are done manually and require digitization to improve accessibility and efficiency in producing desirable results (Raman 2020; Yusuf, 2020). Addressing these challenges will create an interactable and conducive environment for teachers and learners. The widespread of mobile phones has stimulated the development of mobile extended reality applications for information access in a learning environment to enhance the learning experience and engagement in the entire process of learning for the student (Vasilevski, 2020). Indoor navigation is a challenge for visitors in unfamiliar buildings or environments (El-Sheimy, 2021a). Navigation within learning institutions is an existing challenge in many institutions around the world especially for new visitors, while locating services like offices, classrooms, libraries, and washrooms within unfamiliar buildings.

Higher learning institutions in Tanzania particularly the case of Nelson Mandela African Institution of Science and Technology (NM-AIST) located in Arusha, stand out as premier academic and research-based establishments dedicated to fostering education and training. Over the years NM-AIST has collaborated with various industries, research institutes, and academic entities, both governmental and non-governmental, and established partnerships with different academic institutions in Africa and around the world, with the focus on sharing knowledge, student exchange, and collaboration. In doing so the core mission is to cultivate a learning environment that empowers individuals to develop innovative solutions, hence contributing significantly to the advancement of science and technology in the context of African development and global progress by exchange programs that aim to enhance student skills through these partnerships (Kemhe *et al.,* 2022). However, indoor navigation is a challenge in NM-AIST for visitors, new students, and staff when trying to locate facilities within the campus's buildings.

Another case of Baden-Wuerttemberg Cooperative State University (DHBW) an institution among NM-AIST's partner institutions also has indoor navigation challenges. The DHBW is the pioneering institution of higher learning in Germany that combines academic coursework with practical training (DHBW, 2020). Implementation of the indoor navigation system to assist in locating services, offices, classrooms, washrooms, and emergency exits remains challenging for visitors, new students, and staff especially in unfamiliar buildings (Magsi *et al.,* 2021). Within higher learning institutions different buildings with different resources and facilities require access from different groups including students, staff, and visitors. Having a navigation system to navigate within these buildings prioritizes seamless navigation and fosters a conducive learning atmosphere. As a result, this helps to cultivate an inclusive culture, implement effective and engaging teaching methods, and provide access to resources and technologies essential for enhancing the educational experience (Bovill, 2020).

The implementation of indoor navigation focused in this study considered indoor navigation assistance for the main administration of NM-AIST, and the primary building of DHBW which are shown in Fig. 1 and Fig. 2 respectively. Figure 1 shows multiple buildings, including the administration block which houses the majority of staff offices, divided into five wings: wing A, wing B, wing C, wing D, and Wing E. Figure 2 shows DHBW's main building with seven flows divided for offices, classrooms, library, laboratories, and other facilities. This project aimed to develop an accessible augmented reality application to enhance indoor navigation in higher learning environments, using the case of NM-AIST and its partner university, DHBW. Built as an open-source, the application incorporated features for visually impaired users. The overarching goal was to ensure an inclusive experience for all users.

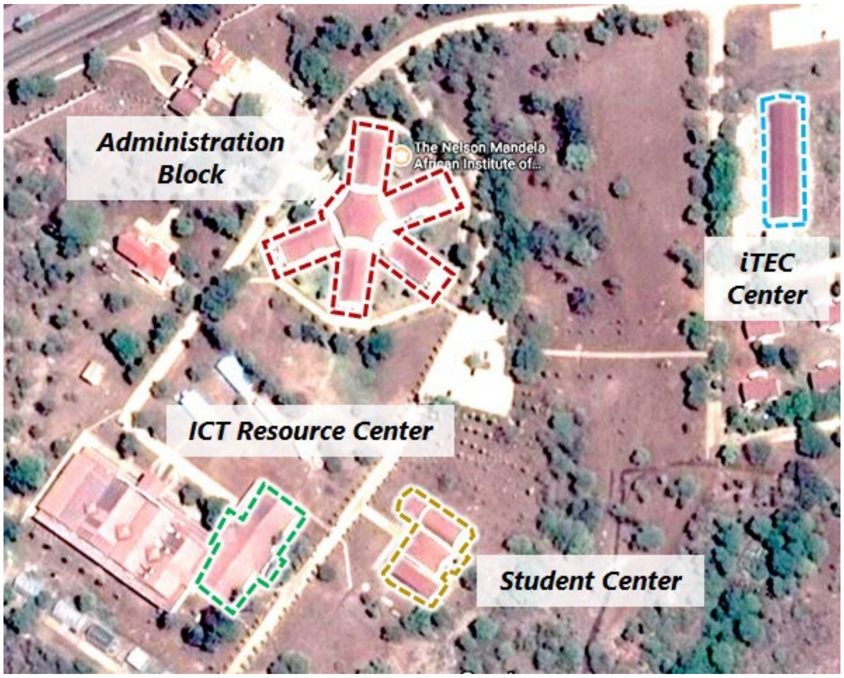

Figure 1: **Aerial map of NM-AIST showing Administration block**

Figure 2: **Duale Hochschule Baden-Württemberg Main building**

1.1.1 Augmented Reality Technology

Augmented reality is defined as an emerging technology that allows the combination of real-world and digital content by projecting these digital contents on top of the real world to produce additional and valuable information for users (Randy *et al.,* 2023). Figure 3 shows the virtuality continuum where augmented reality, which is a subset of mixed reality, is a technology that enhances a user's real-world perception with virtual content like audio, video, images, and text (Rauschnabel *et al.,* 2022).

Augmented reality technology was first used to teach pilots for airlines and the Air Force in the 1960s. Since then, it has been embraced for usage in a variety of industries, including entertainment, mapping, transportation, health, and education (Shidende, 2021). Augmented reality and virtual reality have brought about another dimension for data visualization and the creation of virtual space for educating the new generation (Liu *et al.,* 2020). The visualization is extended more in augmented reality and gives a better experience by presenting data in 2D and 3D in the field of vision.

Augmented reality (AR) has revolutionized user interaction by integrating digital images and 3D models into real-world environments in real-time, according to Romli *et al.* (2020). This innovation has driven the advancement of spatial computing, leading to the development of adaptive applications and enhancing accessibility for navigation. Furthermore, AR has introduced an innovative approach to information visualization within spatial computing, offering fresh perspectives and opportunities for users (Rocha & Lopes, 2020).

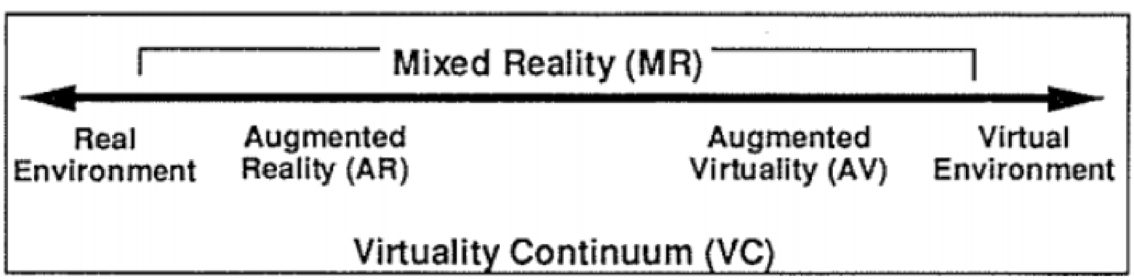

Figure 3: Virtuality continuum

1.1.2 Benefits of Augmented Reality

The benefit of AR is increasing as its applications increase, AR has led to a new pedagogical approach to education and learning with increased engagement. Teachers and trainers can utilize AR in their practice to supplement traditional teaching practices to their students through the creation of AR learning experiences (Alzahrani, 2020a). In the business setting, adopting AR technology offers competitive advantages. The AR technology enables businesses to engage with audiences, communicate messages, and deliver distinct experiences, fostering customer trust and enhancing brand recall (Diana *et al.,* 2023). Beyond business, AR also benefits the medical field, offering dependable methods to demonstrate medical procedures while reducing costs (Kan-Yeung *et al.,* 2021). Overall, AR's advantages are manifold. Its core purpose is to enhance user experience by superimposing digital content onto the real-world environment, fostering deeper understanding and interaction.

1.1.3 Examples of Augmented Reality Applications

There are various examples of augmented reality applications in different fields. Some of these examples are highlighted in Fig. 4 and 5, showing the application of AR in Medicine and tourism respectively. Figure 4 shows the 'HoloHuman' AR app displaying a virtual cadaver on a real examination table. Using a HoloLens headset, the moderator can interact with both the model and the user interface (Dhar *et al.,* 2021). Figure 5 illustrates how tourism and hospitality marketers can use AR to address tourists' concerns. They can offer real-time travel aid and enhanced maps featuring markers and details about shops, grocery stores, tourist sites, gas stations, hospitals, emergency services, banks, post offices, cafes, gyms, and cinemas (Shabani *et al.,* 2019).

Figure 4: Application of AR in medicine

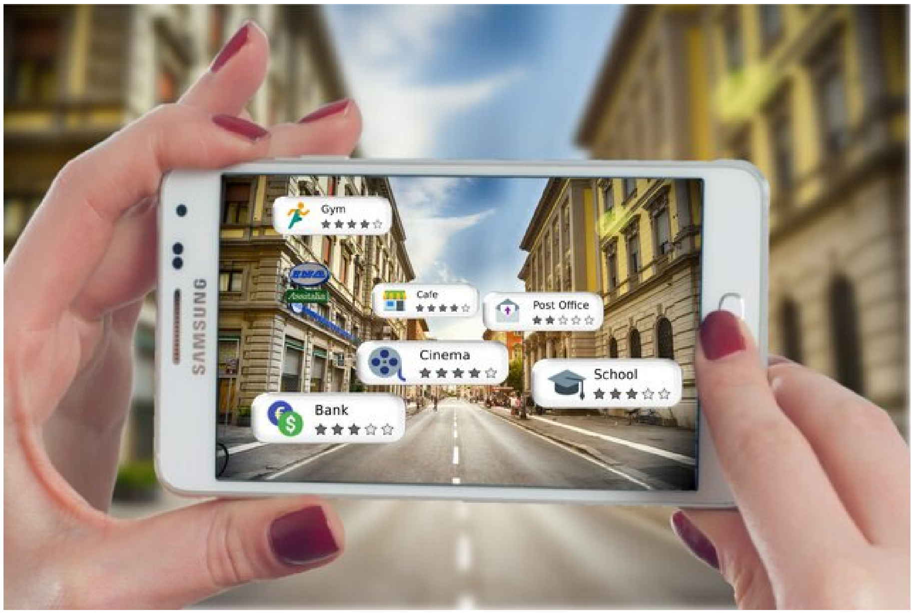

Figure 5: Application of AR in Tourism

1.2 Statement of the Problem

Navigation is a characteristic of all human beings and it involves moving from one place to another to fulfill basic needs or services (Ekstrom *et al.,* 2017). Navigating inside buildings with complex layouts or unfamiliar areas can be particularly challenging for newcomers or visitors in higher learning institutions. Visitors, new students, and staff often face difficulties when searching for various resources or facilities within these environments. This challenge becomes even greater when individuals try to ascertain the prior availability of office occupants they wish to visit. The issue is particularly difficult for people with disabilities, such as visual impairment (Jeamwatthanachai *et al.,* 2019). Various methods, such as posters, notice boards, and direction arrows, have been deployed to guide and give navigation directions to users (Braun *et al.,* 2021). However, these methods aren't always effective, especially when it comes to those with a disability such as visual impairment. Although the advancements in technologies have led to the development of tools and applications to aid navigation across various settings (Díaz-Vilariño *et al.,* 2023), the challenges in indoor navigation persist. Specifically, technologies such as WiFi, RFID, and NFC still face challenges like accuracy, accessibility cost, and security in indoor navigation (Nguyen *et al.,* 2021). The use of extended reality technologies, notably virtual reality

(VR) and augmented reality (AR) has shown significant benefits in various contexts, particularly in education, where they enhance interactive learning and increase student motivation (Misso *et al.,* 2019). Augmented reality, in particular, has been effectively applied in developing indoor navigation systems. These AR-driven systems are recognized as promising solutions for indoor navigation challenges, as they assist users by intuitively superimposing visual data onto physical environments to facilitate navigation (Iatsyshyn *et al.,* 2020) allowing them to search for classrooms, washrooms, offices, or other facilities in higher learning settings (Bai *et al.,* 2020). However, despite the significant usage of this technology, providing accessible and user-friendly supporting tools and applications for users with visual impairments remains a challenge in learning environments (Eligi *et al.,* 2017). Additionally, localization techniques for the identification of reference points toward navigation destinations are still a challenge in indoor navigation. Therefore, this project aimed to enhance indoor navigation by developing an indoor navigation tool to assist individuals, both with and without disabilities, to navigate indoors within higher learning environments more independently and efficiently, focusing on the disabled group of people with visual impairment.

1.3 Rationale of the Project

Khan *et al.,* (2022) indicated that there is a continued need to improve indoor navigation applications to assist people moving around inside unfamiliar buildings, with particular emphasis on accuracy, coverage, cost, power consumption, and localization principles. A variety of methods have been employed to enable indoor navigation, including GPS, Infrared, WiFi, Bluetooth, ZigBee, and NFC (Verma *et al.,* 2020). Among these solutions, augmented reality has shown its effectiveness, especially when combined with visualization techniques that can enhance the indoor navigation experience by providing users with a clear view of different objects (Cankiri *et al.,* 2020; Ekanayake *et al.,* 2022). However, there is still less attention on the impact of augmented reality on route learning (Yount *et al.,* 2022). The addition of 3D information to the real world through augmented reality technology enables users to access supplementary spatial information. This feature of augmented reality makes it an absorbing technology for the development of cartographic applications (Dickmann1 *et al.,* 2021). Few indoor navigation applications using augmented reality have been developed with different features and methodologies across different settings (Joshi *et al.,* 2020), however, there is still a challenge in accessibility for these technologies to cater to people with different abilities. Considering the goal of leaving no one behind in the process, inclusivity is among the features to be taken into account during the development of different products. Users with visual impairment, in particular, depend on assistive technology or support from a sighted or skilled person to assist them when they want to access different services in settings such as higher learning institutions (Kisanga *et al.,* 2022). There is still a gap in addressing the importance of accessibility in navigation for creating inclusive learning environments. Furthermore, the cost-effectiveness of available solutions is still a challenge since some require subscription payment for different features and functionalities (Mohebbi *et al.,* 2017). This project aimed to develop an indoor navigation application that will be cost-effective, optimized, and with a degree of accuracy and provide methodologies that will contribute to indoor navigation technologies to researchers and developers to utilize the same technique and approach, ultimately resulting in the potential for further development and scaling of the project.

1.4 Project Objectives

1.4.1 Main Objective

The main objective of this project is to develop an accessible augmented reality application to enhance indoor navigation in higher learning institutions.

1.4.2 Specific Objectives

The following specific objectives were used to achieve the main objective:

(i) To identify the requirements for developing an accessible augmented reality application for indoor navigation and a web portal for updating staff office availability status in higher learning institutions.

(ii) To develop an accessible augmented reality application for indoor navigation and a web portal for updating staff office availability status in higher learning institutions.

(iii) To validate the developed accessible augmented reality application for indoor navigation and a web portal for updating staff office availability status in higher learning institutions.

1.5 Project Questions

(i) What are the requirements for developing an accessible augmented reality application for indoor navigation and a web portal for updating staff office availability status in higher learning institutions?

(ii) What is the design of an accessible augmented reality application for indoor navigation and a web portal for updating staff office availability status in higher learning institutions?

(iii) How can the validation of the developed accessible augmented reality application for indoor navigation and a web portal for updating staff office availability status in higher learning institutions be carried out?

1.6 Significance of the Project

This project aims to enhance accessibility and navigation for students, staff, and visitors within the learning environment. By providing visual navigation aids, it will improve the navigation experience, save time and costs, and promote innovation in educational technology. The project specifically aims to address indoor navigation barriers, fostering inclusivity for all, including individuals with disabilities focusing on the visually impaired, through the use of augmented reality technology.

Making this project open source to ensure easy customization so other higher learning institutions can access and customize the solution to fit their needs, reducing reliance on costly proprietary software. Additionally, knowing the availability status of the office occupants that visitors intend to visit will serve time since visitors can make decisions based on this information instead of visiting the office physically and missing out.

The outcomes and findings from this project will lay the groundwork for future research on navigation within educational settings, both in Tanzania and globally. Consequently, this project has the potential to advance knowledge and contribute to the development of more inclusive learning environments worldwide.

1.7 Delineation of the Project

This study intended to development of an innovative indoor navigation application aimed to optimize navigational experiences at NM-AIST and DHBW by harnessing the power of augmented reality technology. Embracing the growing concept of a smart campus, a learning environment that fosters dynamic interactions between students/users and their IoT-enabled surroundings. This project intersects with the evolving narrative of smart cities. The developed application was optimized to cater to users with visual impairment by including accessibility features that can assist them during indoor navigation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter defines essential terms for this study and reviews AR-based indoor navigation systems from scholarly perspectives. It also summarizes related works and highlights technical gaps.

2.2 Augmented Reality Use Cases

Augmented reality blends real-world interaction with virtual elements, enhancing objects with computer-generated sounds, videos, or images. This technology, over the years, has impacted fields like industry, entertainment, medicine, education, tourism, and others (Garzón, 2021). Augmented reality applications can be accessed using different devices, including AR headsets, smartphones, and computers. Unlike, Virtual Reality, which requires specialized equipment, AR applications are accessible to anyone with a smartphone and offer a unique bridge between the physical and digital worlds (Gomes *et al.,* 2020). Among use cases of AR is in indoor environments, AR offers real-time navigation solutions by pinpointing people or objects using radio waves, magnetic fields, and additional sensors (Samarin, 2020). These solutions provide guidance accentuated with visual aids such as overlaying arrows, facilitating straightforward navigation. Through device architecture, AR ensures seamless implementation of these indoor navigation systems and facilitating straightforward navigation (Lim, 2020). Through device architecture, AR ensures the seamless implementation of these indoor navigation systems (Lim, 2020). The AR technology is noted for its transformative effects. It fosters both collaborative and creative learning while significantly increasing aspects like engagement, motivation, focus, interactivity, participation, concentration, retention, spatial skills, and information accessibility (Alzahrani, 2020b). In the competitive business landscape, many companies are yet to harness AR's full potential. Those who find themselves with a significant edge, integrate AR into their marketing and service offerings to differentiate themselves in a saturated market (Alotaibi, 2021). Augmented reality has heightened user interaction and engagement when users access platforms like online stores and in-store experiences (Singgih *et al.,* 2021). Improving understanding of products by including technologies like QR codes, product labels, interactive ads, immersive catalogs, and innovative signage. Furthermore, AR training modules are reshaping how businesses evaluate employee progression and performance, granting them the ability to gain precise insights into the effectiveness of their training programs. One of the subtle yet profound advantages of AR is its cognitive efficiency (Montoya *et al.,* 2020). Lastly, AR aids in problem-solving and technical troubleshooting without overwhelming the user's cognitive capacity (Li *et al.,* 2021). Moreover, when combined with Artificial Intelligence, AR plays a pivotal role in reducing language barriers and enhancing the overall user and customer experience (Bhandari *et al.,* 2019).

2.3 Indoor Navigation Systems

The demand for Indoor Positioning and Navigation (IPIN) systems is on a steep upward trajectory, with projections indicating a Compound Annual Growth Rate (CAGR) of 38.2%. The market, which was valued at USD 4.82 billion in 2016, is expected to surge to approximately USD 28.2 billion by 2024 (Goldstein, 2019). This growth is contributed by technological advancements and the increasing number of smartphone users, which have stimulated the development of indoor navigation apps. These applications are essential for aiding users in navigating unfamiliar buildings, thereby enhancing mobility (El-Sheimy, 2021).

Despite the growing market, facilities such as healthcare over 65% remain unacquainted with Indoor Location Systems, as highlighted in a study conducted by Goldstein (2019). This gap highlights the significant untapped potential for indoor navigation applications not only in healthcare but also across various sectors including higher education, industry, aviation, and malls (Deng *et al.,* 2022; Perez-Navarro *et al.,* 2022) .

Ramtohul and Khedo (2020) identified key metrics for evaluating indoor navigation positioning techniques, emphasizing accuracy, precision, and computational load. Accuracy, defined as the shortest Euclidean distance between estimated and exact locations, increases as this distance decreases. While accuracy is critical for positioning system design, it must be balanced with computational load, which measures the energy consumption required for position determination. This load can be categorized as high (H), medium (M), or low (L). Precision, the second most important parameter, evaluates the consistency of a technique's estimations. Additionally, accessibility is an important aspect of any developed system; it ensures usability for all users irrespective of their challenges in terms of accessing systems (Hamid *et al.,* 2020). However, application developers assume users are of the same ability and forget to consider accessibility features for different users (Kamaghe *et al.,* 2020).

Positioning or localization can utilize various techniques, including proximity localization, RSS localization, AoA, time-based methods, and sensor-based localization. The descriptions of these techniques are highlighted below:

(i) Proximity localization detects the nearest objects to a base station (BS) using Cell ID combined with Time of Arrival (TA) or Received Signal Strength (RSS), relying on identifying the closest transmitting cell towers to estimate proximity.

(ii) RSS localization estimates the location of a mobile device using signals from nearby access points (AP) through methods such as trilateration, which calculates location by measuring distances using circles, spheres, or triangles, and fingerprinting, which captures a radio map of values and matches them against pre-stored signatures to pinpoint the location (Ibnatta *et al.,* 2022).

(iii) AoA (Angle of Arrival), measures the angle between the direction of an incoming wave and a reference direction, using triangulation with AoA data from two or more BSs (Ibnatta *et al.,* 2022).

(iv) Time-based techniques, record a signal's Time of Flight (TOF) to estimate a mobile device's location, employing methods like Time of Arrival (TOA), Time Difference of Arrival (TDOA), and Round-Trip Time (RTT), which can use various signals such as radio frequency, infrared, acoustic, and ultrasound (Ibnatta *et al.,* 2022).

(v) Sensor-based localization, uses smartphones' onboard sensors like gyroscopes, accelerometers, and magnetometers, with methods including Dead Reckoning (DR), which calculates position from the last known location assuming direction and speed or distance traveled, and landmark identification, which classifies specific spots like stairs or elevators by their sensor patterns to aid in location recognition (El-Sheimy, 2021a).

2.4 AR-based Indoor Navigation Systems

Augmented reality-based indoor navigation systems have been implemented in different settings, including in shopping malls, airports, and tourism centers among others (Liu & Meng, 2020). The AR-based indoor systems work by determining the initial location of a user at the entrance which is sometimes referred to as a point of interest then allowing the user to choose the destination based on the current location (Ullah Khan *et al.,* 2019).

Ullah Khan *et al.* (2019) developed an AR-based indoor navigation system and tested it at the Centre for Academic Information Services (CAIS), University Malaysia Sarawak (UNIMAS). The results proved that the system provides a good platform to show the location information without requiring hardware installation and a strong wireless connection. However, accessibility features were missing in the system to accommodate users with disabilities.

Joo-Nagata *et al.* (2017) performed an experimental study on 143 primary school students and developed an augmented reality pedestrian mobile navigation application with e-learning features for a university setting, aimed at increasing interaction in the learning process. The results indicated that the experimental group scored higher than the control group, which used a non-augmented reality e-learning platform with images from a different location, and had them explained in the classroom by the teacher. However, the study did not take into account accessibility issues or make the application open-source, which would have made it more widely adoptable in other settings.

Cankırı *et al.* (2020) developed an indoor navigation system that relied on markers to aid in navigation. The system utilized a 2D map as its foundation, with various 3D enhancements added to the map to facilitate easy navigation. However, their approach did not take into account the needs of people with disabilities, and they only focused on the 2D plan for pathfinding, leaving behind the focus to include a 3D plan that would incorporate other room features, such as room height, which could have improved the user experience.

Rubio-Sandoval *et al.* (2021) developed an indoor navigation application that utilized semantic web technologies to display routes and provide contextual information about the user's environment. The application relied on detecting environmental characteristics and illumination conditions to accurately track user movements. The system modeled information on plans, routes, locations, and points of interest for each environment to facilitate faster and easier navigation. However, the system did not take into account the needs of individuals with different disabilities and thus did not consider accessibility features for these users.

Huang *et al.* (2020) developed an augmented reality indoor navigation system that leverages Lbeacon and Bluetooth technology on smartphones to determine a user's initial position relative to their destination. The system uses a network of Lbeacons, strategically placed at various waypoints throughout the indoor space, which send signals to the user's device as they approach each beacon. By analyzing the Received Signal Strength Indicator (RSSI) data stored on the user's mobile device, the system can calculate the distance between the user's position and each Lbeacon. Based on this information, the system can provide accurate location information and navigation guidance to the user in real time.

Martin *et al.* (2021) developed a marker-based navigation application using the Vuforia engine. The app uses markers placed at different entrances of a building to identify the user's initial location and destination. To navigate inside the building, the user scans the markers using their phone camera. However, the application requires users to continue scanning markers to identify their destination, which can be a challenge. To improve the user experience, further development is needed to enable the app to provide continuous navigation guidance without the need for repeated marker scans.

In Africa, few studies have reported the implementation of indoor navigation systems (Hatem *et al.,* 2019). These systems are still in high demand because they provide faster and more reliable navigation inside unfamiliar buildings (Goldstein, 2019). However, in Africa and globally different technologies have been used to implement indoor navigation in different settings, such as Radiofrequency (RF) signals, computer vision, and sensor-based solutions. These technologies are more suitable for tracking users in indoor environments (Kunhoth *et al.,* 2020). The emerging application of AR in indoor applications has become an indispensable tool across various sectors, providing enhanced visualization that effortlessly describes complex concepts through immersive visualizations. The adoption of AR as technology for developing indoor navigation systems has increased in recent years both in Africa and globally (Munesh, 2020).

Table 1: Summary of related works

SN	Reference	Problem Addressed	Proposed Solution	Limitations
1	Cankırı *et al.* (2020)	Indoor navigation using a 2D map	A marker-based augmented application for indoor navigation	The application didn't have 3D features No accessibility features for people with an impairment
2	Joo-Nagata *et al.* (2017)	Experimental study on primary school regarding the usage of 2D and 3D navigation application	an augmented reality pedestrian mobile navigation application that includes e-learning features	The application did not have accessibility features
3	Rubio-Sandoval *et al.* (2021)	An Indoor Navigation Methodology for Mobile Devices by Integrating Augmented Reality and Semantic Web	indoor navigation systems based on Augmented Reality and SemanticWeb technologies to present navigation instructions and contextual information about the environment.	Didn't include positioning methods such as WiFi or Bluetooth wireless networks No accessibility features
4	Martin *et al.* (2021)	a marker-based navigation application	marker-based navigation application using the Vuforia engine	Re-scanning of the marker each time while moving from one place to another
5	Huang *et al.* (2020)	an augmented reality indoor navigation system	an indoor navigation system that leverages Lbeacon and Bluetooth technology on smartphones to determine a user's initial position relative to their destination	Not accessibility features No advertisements of the surrounding environment Not enough 3D objects to visualize and enhance the navigation experience
6	Developed solution	Accessible augmented reality application to enhance indoor navigation	Indoor navigation with optimization for users with visual impairment, using voice recognition	Only for the Android platform

2.5 Accessibility in Indoor Navigation Systems

Accessibility relates to the ability to interact or the capacity to engage with environments (Handy, 2020). For those with disabilities, it involves utilizing methods or tech to effectively connect with the environment. In education, accessibility ensures education is accessible to everyone, regardless of capability (Matonya, 2020). Accessible software simply means usable software, this is because accessibility provides the creation and designing of different interfaces for different users. Experts have outlined frameworks emphasizing accommodations, assistive devices, and inclusion for those with disabilities (Eligi, 2017; Burgstahler *et al.,* 2020b). Universal design is a concept that promotes accessibility, practicality, and inclusion for the disabled (Heiman *et al.,* 2020). This model can be applied across different areas, integrating sector-specific accessibility features (Burgstahler *et al.,* 2020). Disabilities differ, leading to multiple interaction methods. Many sectors have added accessibility via technologies tailored for various disabilities (Garcia Carrizosa *et al.,* 2020). Those with visual impairments often rely on third-party assistance or white canes for navigation (Khan *et al.,* 2021). Assistive tech lets the disabled experience life differently. Innovations like indoor navigation systems boost mobility for the blind, enhancing inclusivity and enabling better interaction with their environment (Constantinescu *et al.,* 2022; Cheraghi *et al.,* 2021). However, often accessibility is secondary when creating such applications (Basha-Jakupi *et al.,* 2008; Kamaghe *et al.,* 2020). Presuming all users have the same abilities introduces accessibility issues. Indoor navigation apps for indoor navigation spaces should have accessibility as a core feature, catering to everyone's requirements and bolstering inclusivity and accessibility.

2.6 Technical Gap

The literature review highlights numerous AR applications deployed across diverse sectors, emphasizing a significant demand for AR-based indoor navigation systems in higher education institutions. Despite advancements in indoor technologies, gaps remain in the localization for identification of the initial position of the navigator and the accuracy of the application in guiding from the reference point to the destination point. There is a notable disparity between the distances indicated by the applications and the actual real-world distances. Additionally, the computational load required for navigation significantly impacts device power consumption. Additional concerns include the cost of proprietary software subscriptions, localization techniques, security for system users, and notably, a lack of essential accessibility features. Many existing applications fail to include inclusive design for individuals with disabilities, lacking customization options that would allow adaptability in various locations for more effective assistance. This study addresses these gaps by developing an AR indoor navigation application optimized for people with visual impairments, aiming to enhance navigation efficiency and address the concerns previously reported by scholars.

2.7 Developed System

The proposed accessible indoor navigation application utilizes augmented reality technology to enhance the indoor navigation experience. The application facilitates easy indoor navigation for diverse types of users with more optimization for visually impaired users. By incorporating augmented reality, voice recognition, and 3D visualization capabilities users can effectively choose their destination and navigate from one point to another inside the building. The system determines the user's initial location by utilizing QR code scanning at the starting point, employing WiFi fingerprinting through machine learning techniques, and tracking the device's camera to localize the device using Simultaneous Localization and Mapping (SLAM). Additionally, it provides staff with the ability to update their office availability status using a web portal which ensures visitors receive timely and efficient information about staff office availability. The navigation application was built with open-source licenses, ensuring adaptability and customization. The architecture of the developed system is presented in Section 4.4.1 of Chapter 4.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

In this chapter, we explore the materials and methods leveraged throughout the system's requirement gathering and developmental stages. Here, we discuss the scope of the project, the techniques we embraced to collect data, and the methodologies we followed to develop the system**.**

3.2 Project Case Study

This study used a case study NM-AIST which is located in Arusha Tanzania and DHBW Heidenheim located in Heidenhe im Germany which is a partner University to NM-AIST. The selection for the case study area followed the course of internship placement. The main placement for the internship was NM-AIST where the requirements for developing the application and web portal were gathered. The internship was carried out in six months and three months were spent at NM-AIST and another three months was spent on a research visit to the Augmented Reality Learning and Authoring (AuReLiA) lab at DHBW. The development was carried out in the three months of the research visit and a pilot testing was tested at DHBW aiming for possibilities of application customization in other settings. Upon completion of the research visit, the development continued at NM-AIST and more testing was conducted and later validation of the application and the web portal.

3.3 Target Population and Sample Size

The project's target population was staff, students, and visitors including those with visual impairment. The study employed a non-probabilistic sampling method to obtain the sample size for the study. Baltes and Ralph (2022) defined non-probabilistic sampling as all sampling techniques that don't involve randomness in selecting a sample size, including respondent-driven sampling, purposive sampling, convenience sampling, and, snowball sampling.

During the study, a total population of 60 respondents was selected using purposive sampling techniques. Purposeful sampling is a sampling technique where the researcher selects the sample size based on his or her knowledge of the population about the research goal (Mweshi *et al.,* 2020).

The distribution of respondents was 20 staff, 20 students, and 20 visitors including people with visual impairment.

3.4 Data Collection Methods and Tools

The study utilized a qualitative approach for primary and secondary data collection. Data were collected between April and June 2023 during the internship period. To achieve the collection of primary data semi-structured interview method and focus group discussions were employed. A semi-structured interview is a type of interview that allows a researcher to better understand the respondent's perspective on the problem investigated instead of generalizing an understanding of the problem (Adeoye *et al.,* 2021).

Focus group discussion is a method that is normally led by a moderator or an investigator with a small group of people or participants to discuss a given topic (Adeoye *et al.,* 2021). In this study, a focus group comprising 20 students was utilized to gather user stories for the development of an augmented reality indoor navigation application. The generation of user stories followed the format adopted from the template suggested by Amna and Poels (2022) which has three segments that include a role that describes a type of system user that wants the system to achieve or do something, a goal that describes the action to be performed by the system in support of the user, and a benefit that provides the rationale for this action, this user story is then written in the form of "*As a 〈role〉, I want 〈goal〉, so that <benefit>".*

To understand the potential benefits of a web portal for indicating staff availability in the office, interviews were conducted with 20 staff members at the NM-AIST institution. The interview aimed to explore how such a portal could facilitate communication with visitors during their office visits. In parallel, 20 visitors, including those with visual impairments, were interviewed to identify the challenges encountered in indoor navigation and to determine the features that could be integrated into the AR application to enable independent and unassisted indoor movement. Online and physical means were used to reach out to participants during data collection. The sample size used in these methods was selected using purposeful sampling techniques.

Additionally, the research involved a review of documents to gather secondary data. The reviewed documents included building blueprints (floor maps) from NM-AIST and DHBW, as well as reviewing related documents on indoor and facilities management. This review was aimed at gathering an understanding of indoor navigation implementation within these institutions.

3.5 Data Analysis

Data analysis was conducted to analyze the collected data from users for the generation of non-functional and functional requirements which were presented in user stories. Using thematic analysis which aims to produce themes from the data a journaling technique Nowell *et al.* (2017) was used to annotate and highlight different themes of the data in user stories. User stories are pieces of requirements within the agile methodology, they are written in a sentence using natural language to express the functionalities of different units of the system that is to be developed (Tsilionis *et al.,* 2021). Journaling is the manual process of annotating and highlighting the data and then writing down the researchers' themes of the data to obtain the functional requirement. After obtaining an epic of user stories, which simply means a large body of user stories, they are then prioritized to decide which user stories should start from epic which is the. During user story prioritization user interactions are outlined to identify what to build next in sprints. Both functional and non-functional requirements were also analyzed to understand the requirements of the system to be developed (Raharjana *et al.,* 2021).

3.6 System Development Approach

The system development utilized scrum practices, which are among agile practices with an incremental approach and iterative to manage large tasks in development which has frequent changes of business requirements. This methodology was selected to ensure fast development of the project and also the flexibility to accommodate changes when they occur. It involves continuous communication between the developer and the users while focusing on the development of sprints (Hema *et al.,* 2020).

Scrum practice contains five development phases in software development when it is viewed in the Software Development Life Cycle framework. These five phases are product backlog creation, sprint planning, working on the Sprint, testing/demonstrating, and retrospective. Phases are described in Fig. 6. Unlike other Software development life cycles (SDLCs) like waterfall methodology which are rigid Agile development involves frequent delivery of new versions for evaluation. Other techniques that are involved in agile such as Extreme programming and Kanban among many others, in which tasks and activities are carried out iteratively to achieve faster feedback and more frequent delivery of working software (Bica *et al.,* 2020).

User requirements can be presented or written in many ways including requirements lists, use cases (UC), user stories (US), and formal specifications. Most agile practices present user requirements using user stories (Ecar *et al.,* 2018). User stories that were obtained after analysis in this study were implemented in sprints. To ensure that sprints are manageable and deliverable within a maximum of three-week timeframe, small user stories were combined into a single sprint, and large user stories were broken down into manageable small user stories.

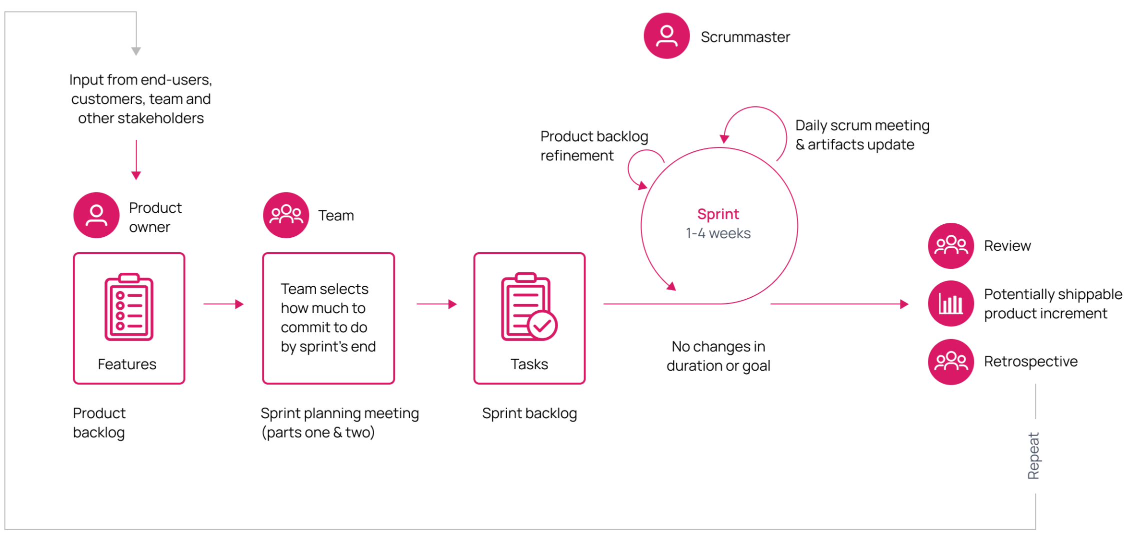

Figure 6: Scrum agile development methodology

3.6.1 Product Backlog Creation

The product backlog is the initial step in scrum practices, in this study after the collection of requirements, it involved meeting with supervisors to discuss all activities that will be included in the development of the project. In this step, all demands and features to be developed are pointed out, and the list of all activities that will be developed is documented in the product backlog (Carvalho, 2011). Professor Mobs an industrial supervisor and a certified scrum master was responsible for making sure all the scrum practices were being followed, and Mr. Shidende who is also an assistant industrial supervisor assumed the role of a product owner during product backlog creation.

3.6.2 Sprint Planning

Sprints are the main practices in scrum practices, which means the time allocated to accomplish an amount of work as defined in the product backlog. Sprints vary from one to four weeks, depending on how big the sprint is. Sprint planning involves planning meetings where the team plans how many sprints they will have and how they will be implemented in what time duration. The output of sprint planning is a sprint backlog, which is the subgroup of the product backlog (Carvalho, 2011).

3.6.3 Working on the Sprint

The time for implementation of each sprint was 14 days (two weeks) during the development phase of the system, bi-weekly meetings with industrial supervisors were conducted to discuss what had been done in the previous two weeks and which items from the product backlog would be tackled during the upcoming two-week sprint. During the meetings, three questions were set to be answered which are what was done since the last meeting? What will be done till the next meeting? Is there any obstacle to the accomplishment of your tasks? These questions were expected to be answered in every meeting. After every 14 days sprint was expected to be released as a working component, depending on the user story. Some sprints extended to 3 up to 4 weeks depending on how big the user story was.

3.6.4 Testing

Software testing in Agile methodology simply means assuring the quality of a product or software to be developed. During the system testing stage, both functional and non-functional requirements are examined to see if they meet user requirements. This process aims to ensure that the final product meets the needs and expectations of stakeholders and end-users. Before delivering any unit from a sprint or conducting any integration, testing is performed using a test-driven development approach to ensure that testing is an integral part of the development process (Barraood *et al.,* 2021). Test cases were written alongside the requirements, and development was driven by testing to ensure that the software meets the user requirements and produces an expected outcome. This approach encompassed both Test Driven Development (TDD) which involves writing test cases followed by coding and Acceptance Test Driven Development (ATDD) methodologies as illustrated in Fig. 7 which are based on predefined acceptance test criteria where each part of the project must be accepted before being integrated with other units (Moe, 2019). Testing was conducted iteratively during each sprint and during the integration of different sprints, lastly, the overall system was tested to check if it runs seamlessly to achieve the system goal of the developed system.

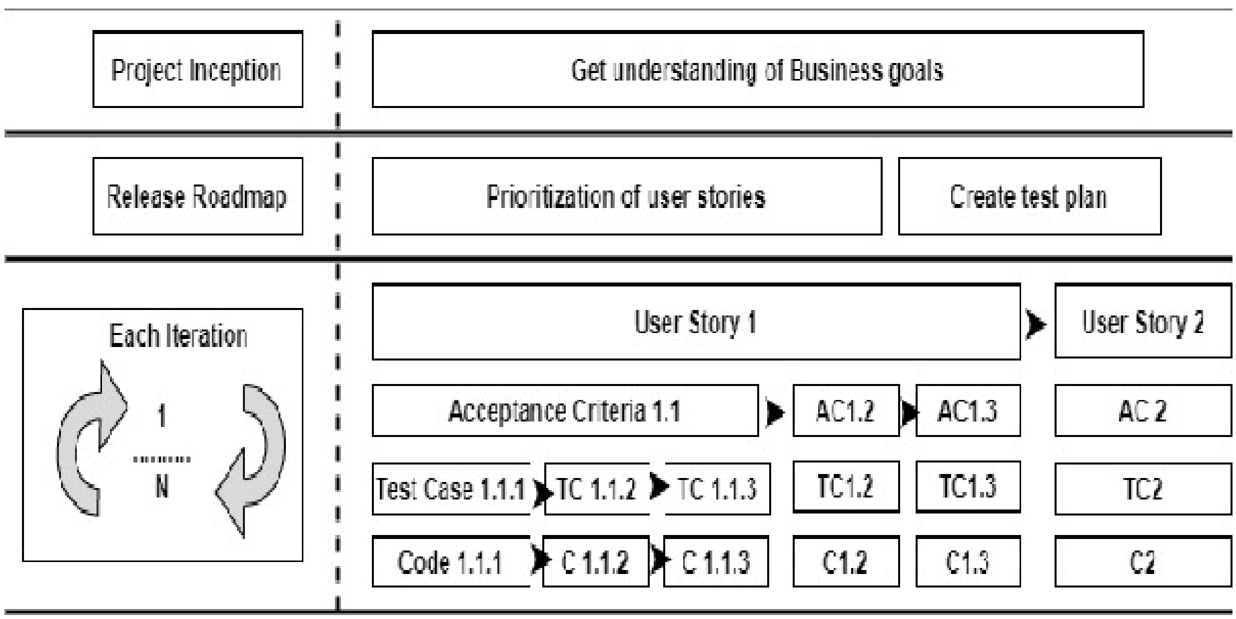

Figure 7: Testing Iteration during Agile Development

3.6.5 Sprint Retrospective

Retrospective in scrum involves meetings that aim to inspect, fix, and improve their development process. This involves checking whether the sprint has extended the allocated time and what is to be done to accomplish the sprints without being outside of the scope (Przybyłek *et al.,* 2022). During bi-weekly meetings, a sprint retrospective was carried out as among the agenda of the meeting where sprints were reviewed to see challenges and address them.

3.7 System Design

System design defines an architecture and the skeleton of a system. It defines the behavior of the system in terms of different functional and non-functional requirements (Mekni *et al.,* 2017). The designing phase included also the wireframe design of both the application and web portal. A wireframe is a schematic or blueprint that can be used to facilitate communication and enable programmers, and designers to communicate with customers about the structure of software they are developing (Staino, 2023). User stories were picked, and a design of the interface and features was performed in iteration. The design iteration process was applied in the wireframing front end for the indoor navigation application and web portal. Design iteration may include high-fidelity wireframes, mid-fidelity wireframes, low-fidelity sketches, or diagrams such as sitemaps (Dave *et al.,* 2021). The results of the designed wireframes are presented in Chapter 4, results and discussion. These iterations are described below:

3.7.1 Low-fidelity Sketches

Low-fidelity sketches are sketches that are drawn on a piece of paper by brainstorming between a user and developer, they serve as a skeleton of an application or a web system (Adefris *et al.,* 2022). During the low-fidelity sketching step, several sketches for interfaces were drawn using a pen and a piece of paper following user stories. The process involved a discussion with users to decide which one was the best for developing a desired final product.

3.7.2 Mid-fidelity Wireframes

Mid-fidelity wireframes are the next step after low-fidelity wireframes. In mid-fidelity wireframes, more details are added to the design, including spacing, buttons, and headings (Avdela, 2023). Additionally, during this step, wireframes can be connected to show the flow of information between components of the system or application and how different pages are connected (Chen *et al.,* 2020). In this project, wireframe sketches were used to design mid-fidelity wireframes, which were shared with users for comments and acceptance, and then comments were accommodated.

3.7.3 High-fidelity Wireframes

High-fidelity wireframes are close to the final design, they are realistic and resemble the final product (Shania *et al.,* 2023). The designed wireframes include colors, icons, images, and buttons together with their styling properties (Suleri *et al.,* 2019). These wireframes consume more resources in terms of design time compared to low and mid-fidelity wireframes (Li *et al.,* 2021). High-fidelity wireframes are used for projects whose interfaces have already been approved by stakeholders. The Figma designing tool was used to create high-fidelity wireframes of approved interfaces.

3.8 System Development Tools

This section outlines the software and hardware tools that were used during the development, including game engines, editors, database management systems and database administration tools, scripting languages, application programming interface, and scripting interpreting tools. All these tools used were open-source to ensure that they provide flexibility and ensure smooth usage during development and maintenance. The tools used are described below.

3.8.1 Game Engine

A game engine is a software that enables the creation or development of a video game Andrade, 2015). Unity is among game engine software developed by Unity Technologies and released first in 2005 at the Apple Worldwide Developers Conference as a game engine for Mac OS X game engine. Since then, the engine has been upgraded and extended to support a variety of platforms including desktop, mobile, console, and virtual reality. During the development, a game engine was used because it contains libraries and tools that support augmented reality development. These tools include ARKit and ARCore which are for Apple and Android respectively. This project used ARCore tools inside Unity to build an indoor application.

3.8.2 The 3D Modeling Software

The modeling of three-dimensional (3D) objects is the creation of the 3D object using computer-aided design programs (Triepels *et al.,* 2019). In this project, we used Blender to model some of the components used in the application. Other components were obtained from SketchFab which is a 3D modeling website platform that publishes, shares, discovers, buys, and sells 3D, VR, and AR content.

3.8.3 Editors

In writing scripts, Visual Studio code IDE was used. This IDE is an open-source code editor that supports the writing of code in many programming and scripting languages including C#, HTML, PHP, CSS, and JS (Larsen *et al.,* 2010). It can be used to compile and debug codes during writing, also it has an auto-complete feature during code writing which makes writing easy and faster. The same IDE, Visual Studio code was used in writing scripts for both application and web portals.

3.8.4 Scripting Languages

Scripting languages are programming languages that are used to write computer programs, systems, and applications (O'Shea, 2020). Different instructions of how the application or systems should behave or solve a certain problem are normally stated or written using scripting languages. In this project we used C# scripting language to write instructions for the application, C# scripting language is the main language that is used in the Unity game engine. Methods and classes were written in C# to implement and code different units and functionalities of an application. In the development of a web portal, we used PHP, HTML, Python, JSON, CSS, and JS to code the functionality and features for the web portal on both the back end and front end. Additionally, bootstrap was used to code a front end, which is an open-source content management system built in HTML, CSS, and JS.

3.8.5 Application Programming Interfaces (APIs)

APIs are a set of defined rules in software development that govern the communication between two applications or software. It serves as a layer of intermediary processing data transfers between systems, enabling businesses to make their application data and functionality available to internal departments, business partners, and outside developers (Ajam *et al.,* 2020). During development, different APIs were used to create communication between the availability status web portal and the indoor navigation application. Integration of speech recognition was also implemented by using IBM Watson APIs. Figure 8 illustrates the functioning of APIs. In this process, a web application sends a request via an internet connection to the web server, aiming to retrieve specific information from the database. Subsequently, the web server responds to this request with the relevant information or service, facilitated through an API.

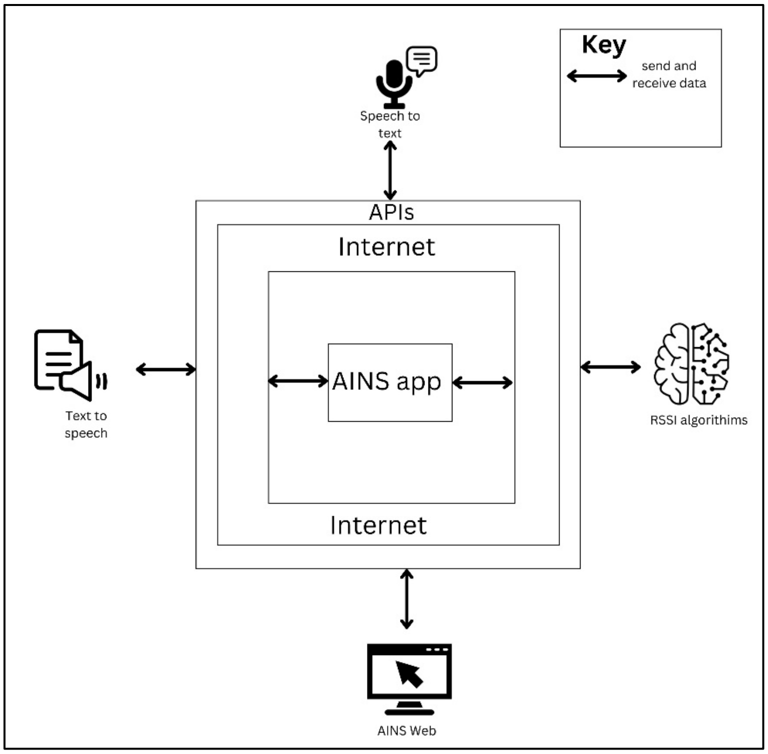

Figure 8: How API works

3.8.6 Database Tools

The database management system, MySQL was used as a backend database for a web portal, and it was created and implemented using phpMyAdmin. The MySQL is an open-source database management system that creates a platform for developers to write and manage databases (Christudas, 2019). The MySQL databse was selected because it supported the integration of web portal and application and it was easy to implement calling of database from the application.

3.8.7 Website Accessibility Evaluation Tools

Web accessibility is defined as the ability to access a website regardless of the hardware or software employed, and independent of language, culture, or the physical or mental abilities of users (Nuñez *et al.,* 2019). An accessible website complies with W3C standards for accessibility. Various tools are available to assess website accessibility (Abascal *et al.,* 2019). This study employed a popular tool to evaluate the web portal designed for updating staff status availability which is AChecker web accessibility (ACHECKS, 2024) where the user types the address of the website and the tool traversal in the files to check for accessibility standards of the written codes as shown in Fig. 9. The selection of this tool was based on its widespread popularity and usage. The evaluation, considered a non-functional requirement, is detailed in Chapter Four, where the results of the accessibility assessment are reported.

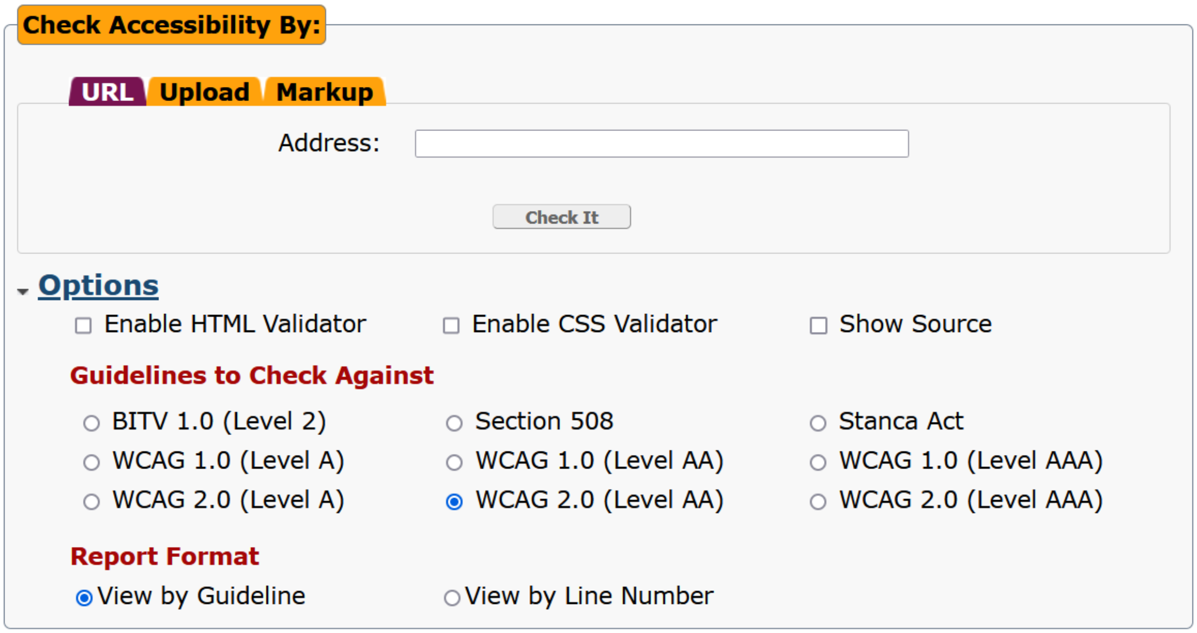

Figure 9: Achecker web accessibility tool interface

3.8.8 Received Signal Strength (RSSI) Localization

This study employed the RSSI fingerprinting method, a localization technique, to enhance the identification of an application user's initial location in indoor settings. The RSSI fingerprinting involves collecting RSSI values from various mapped access points, storing them in a database, and translating these measurements into a coordinate system to establish the device's initial position (Khan *et al.,* 2023) as presented in Fig. 10. A machine learning model was then developed to predict the user's initial location coordinates based on the RSSI signals received. The methods used from data collection through model deployment are outlined below, with deployment results and evaluation metrics presented in the 4.5.3 Section in Chapter 4.

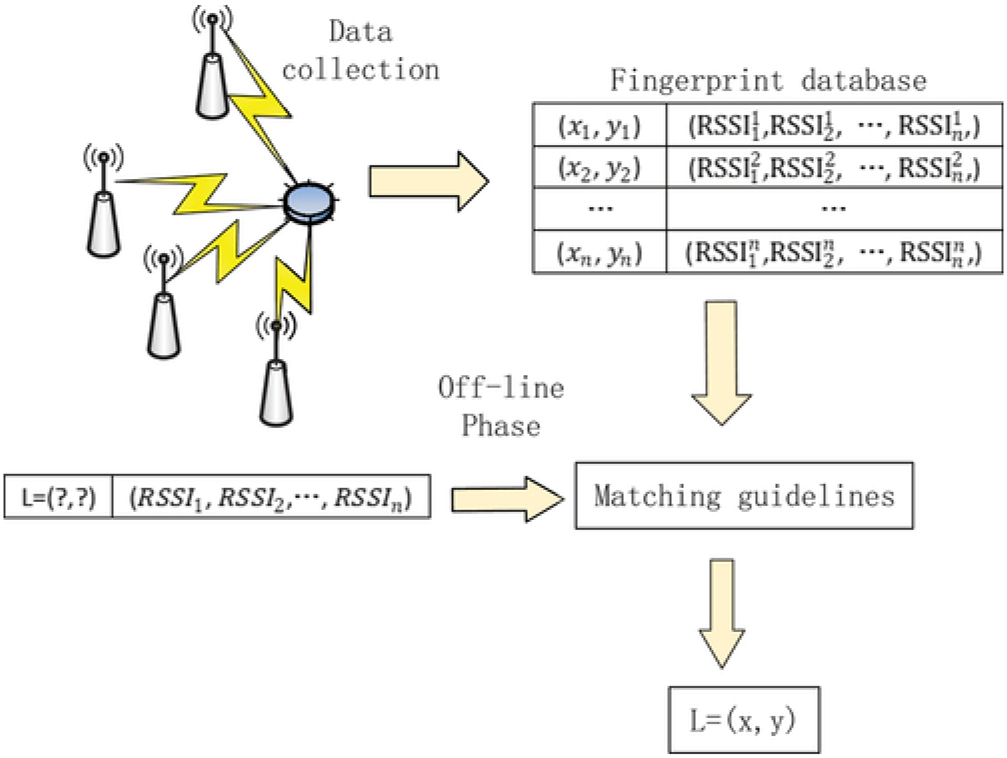

Figure 10: Fingerprinting process with RSSI

(i) Dataset Creation

The Received Signal Strength Indicator (RSSI) datasets were generated by collecting RSSI values from the main entrance of the NMAIST main building. Before data collection, the entrance area was measured and gridded to establish different coordinate points. During data collection, the researcher stood at these coordinate points and used the Airport Utility application to scan WiFi signals from four access points: NM-AIST_D, NM-AIST_B, NM-AIST_C, and CDAC_14, all accessible from the entrance. The dataset was noted for its completeness, with no missing values, and comprised a total of 1000 entries with no missing values, Table 2 presents a snapshot sample of the dataset collected. The then synthetic tool was employed to regenerate data enough for training the model where C-GAN techniques were used to regenerate more synthetic data and more data were generated to form as a result, of having 10 000 datasets, Fig. 11 shows the comparison of original data with synthesized data. The data was then split 20% of the data was used for testing, and the remaining 80% was used for training.

Table 2: Sample of collected RSSI signals

Access points				Coordinate	
NM-AIST_D	NM-AIST_B	NM-AIST_C	CDAC_14	X (Meter)	Y (Meter)
-62	-85	-76	-79	3.56	1.39
-61	-86	-78	-75	3.59	2.59
-68	-87	-80	-85	3.59	3.79
-57	-81	-83	-84	3.59	4.99
-62	-86	-84	-85	3.59	8.59
-64	-86	-90	-89	3.56	11.59
-66	-75	-83	-82	7.15	11.59
-62	-78	-89	-90	8.66	11.59
-69	-88	-90	-90	9.9	11.59
-80	-78	-80	-89	11.3	7.99

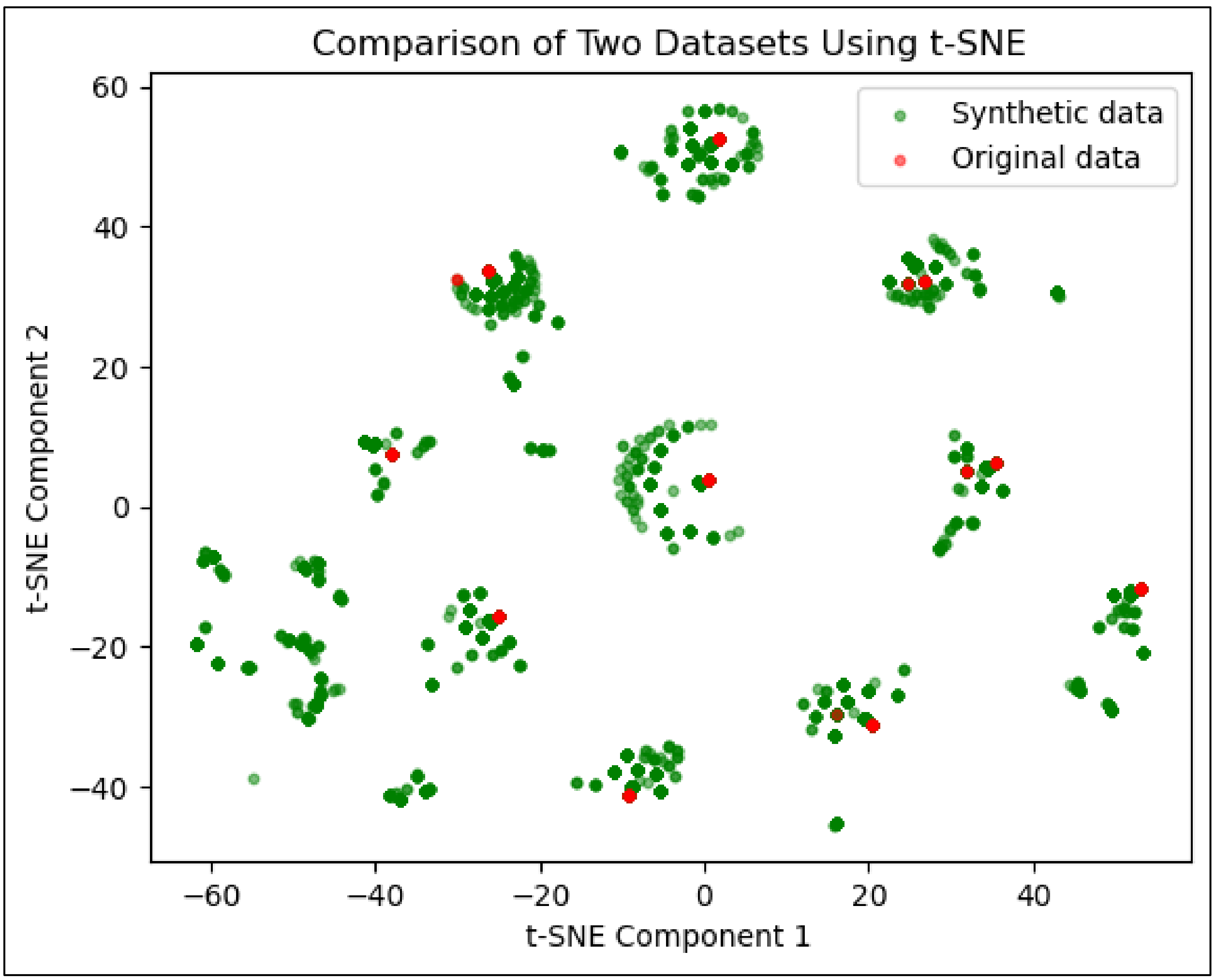

Figure 11: Comparison between original data and synthetical data

(ii) Synthetic Data Generation

Synthetic data refers to artificially generated datasets that contain no identifiable information, created algorithmically from existing original datasets. It serves as a substitute for test data sets of production or operational data, facilitating the validation of mathematical models and the training of machine learning (ML) models (Dankar *et al.,* 2021). This type of data is particularly useful in scenarios were using real data poses deficiency, privacy, or security risks, or when such data is not readily available (Nikolenko, 2019). To generate a more synthetic dataset for RSSI fingerprinting the study used the Conditional Generative Adversarial Network (C-GAN) technique this is because the data used in the study are tabular. The C-GAN is a type of GAN technique that adds the label y as an additional parameter to the generator in the hope that the corresponding data will be generated (Xia *et al.,* 2022).

(iii) Data Pre-Processing

A total of 10 000 datasets were derived from 1000 field-collected datasets, with no missing data recorded due to the primary field-collection method. Data processing was crucial to clean and ensure accuracy before training the model. This cleaning process involved comparing correlations between the original and synthetic data.

(iv) Algorithms for Model Development

During the model development, two regression models, Forest Regressor and K-Nearest Neighbor (KNN) Regressor, were evaluated to determine which algorithm performs better. The choice to use regression models was based on the dataset's composition of continuous values, making these models suitable for predicting and analyzing continuous outcomes (Singh Kushwah *et al.,* 2022). Three evaluation metrics were employed: Root Mean Square Error (RMSE), Mean Square Error (MSE), and Mean Absolute Error (MAE). These metrics are critical for assessing regression algorithms. The RMSE measures the average magnitude of errors between the model's predictions and the actual values, where a lower RMSE indicates higher performance. MSE assesses how close the regression line is to the data points, with a lower MSE indicating more accurate predictions. Lastly, MAE quantifies the average magnitude of the errors in the predictions, ignoring their direction, thus providing a measure of accuracy for continuous variables. The results of the evaluation of these algorithms are presented in section 4.5.3 in Chapter four.

3.9 System Validation

System validation is the process of verifying through analysis and presentation of objective proof that the specifications of the program meet the demands of the user and their intended uses. The validation was conducted in two phases. The first phase took place at NM-AIST, where both the indoor navigation application and web portal were validated. The second phase occurred at DHBW, where a workshop for usability testing was conducted to further validate the indoor navigation application. During system validation, questions were prepared to test and validate the functionality of the web application and indoor navigation application to ensure they met user requirements. The validation process outlined the purpose, procedures, participants, and metrics. Staff, students, and new visitors participated in the validation, ensuring that the application's development was complete and that all requirements were met.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Data collected by Interviews

(i) Interviews from Visually Impaired

Demographic Characteristics of People with Visual Impairment

The aim was to assess the demographic nature of the people with visual impairment. The results, as shown in Table 3, indicate that the majority 50% of the respondents visually impaired were in the age group between 21 -30 while 30 % percent were in the age group between 41-50 and 20% in the age group between 31-40 as presented. Table 3 also shows that 55% of the respondents were female and 45% were male.

Table 3: Demographic characteristics of visually impaired people

Demographic characteristic	Frequency	Percentage (%)
Age		
21-30	10	50
31-40	4	20
41-50	6	30
Total	20	100
Gender		
Male	9	45
Female	11	55
Total	**20**	**100**

Consent to Participate in the Interview

This question was set with the aim of assessing the participant's willingness to participate in the interview process. The results as shown in Table 4, indicate that 100% of the participants agreed to participate.

Table 4: Consent to participate in the interview

Would you like to conduct this interview	Frequency	Percentage (%)
Yes	20	100
No	0	0
Total	20	100

Current ways you Use to Look for Facilities when you are in an Unfamiliar Environment

The aim was to understand the way used by people with visual impairment to navigate and move when they find themselves in unfamiliar buildings or environments. Table 5 shows that 50% of the respondents stated that they rely on asking someone available to help them move around, 20% of the respondents reach their destination by getting directions through a phone call, 15% of respondents rely on personal escort while 15% of the respondents move using the stick or white cane.

Table 5: Current methods visually impaired use to move indoor

Way used	Frequency	Percentage (%)
By asking someone to take me	10	50
By using my stick	3	15
Through phone call	4	20
Through my escort	3	15
Total	**20**	**100**

The need to have a System to Enhance your Indoor Navigation Experience

Figure 12 shows the response to the demand for accessible indoor navigation to help the visually impaired navigate indoors. The 80% of the respondents responded that they needed an enhanced indoor navigation system with accessibility features while 20% of the respondents responded negatively.

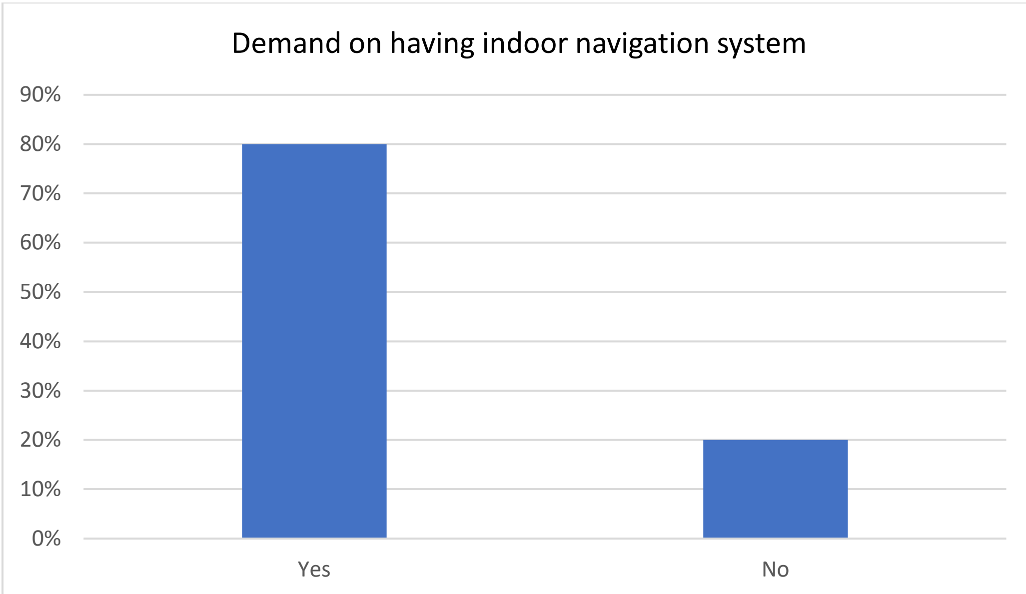

Figure 12: Response about having an accessible indoor navigation system

(ii) Interview with Staff

The interview was conducted with staff aiming to understand how they communicate their office availability to their visitors. The interview aimed to identify the features of a web portal for staff to be able to update their office availability status for their visitors, and to be able to receive information from their visitors.

Years of Work and School

The demographic information included the number of years worked and school from are represented in Table 6. 30% of the staff came from COCSE school, 25% came from MEWES school, 25% came from LISBE school and 20% came from BUSH school.

Table 6: Years of work and staff's school

Demographic character	Frequency	Percentage (%)
School		
MEWES	5	25
COCSE	6	30
BUSH	4	20
LISBE	5	25
Total	**20**	**100**
Years Worked		
1 - 2	10	50
3 - 4	4	20
5+	6	30
Total	**20**	**100**

How do you Provide Direction to Visitors who are Coming to your Office?

This question was set to understand the ways that staff use to provide direction to visitors who are visiting their office. As presented in Table 7, the majority of the respondents 75% utilize phone calls and messages to direct visitors to their offices while 25% are from the receptionist.

Table 7: Ways to direct visitors to the office

Way used	Frequency	Percentage (%)
Through phone call or message	15	75
From receptionist	5	25
Total	20	100

How do you Know who Visited your Office?

This question was set to understand the feedback office occupants get when visitors visit their offices and they were not available when they visited them. Table 8 shows the responses from staff, where 55% rely on the feedback call, 30% don't know and 15% rely on the feedback from the receptionist or secretary.

Table 8: Ways staff knows about who visited their offices

Way used	Frequency	Percentage (%)
Feedback call	11	55
From the receptionist or secretary	3	15
I don't know	6	30
Total	20	100

Availability and Need for the Systems

These two questions were designed to gain insight into how staff currently inform visitors about their availability and to assess the demand for a dedicated system to communicate this information. Table 9 details the methods staff currently use: 40% utilize email auto-responses, 30% notify the receptionist, 20% do not communicate their availability at all, and 10% use phone calls. Additionally, Fig. 13 illustrates the support for a new system to provide visitors with information regarding staff availability in their offices. Remarkably, 100% of respondents expressed a need for such a system, while none saw it as unnecessary.

Table 9: Ways staff update their visitors about their availability

Ways used	Frequency	Percentage (%)
Notify receptionist	6	30
Email auto response	8	40
I don't	4	20
Through calls	2	10
Total	20	100

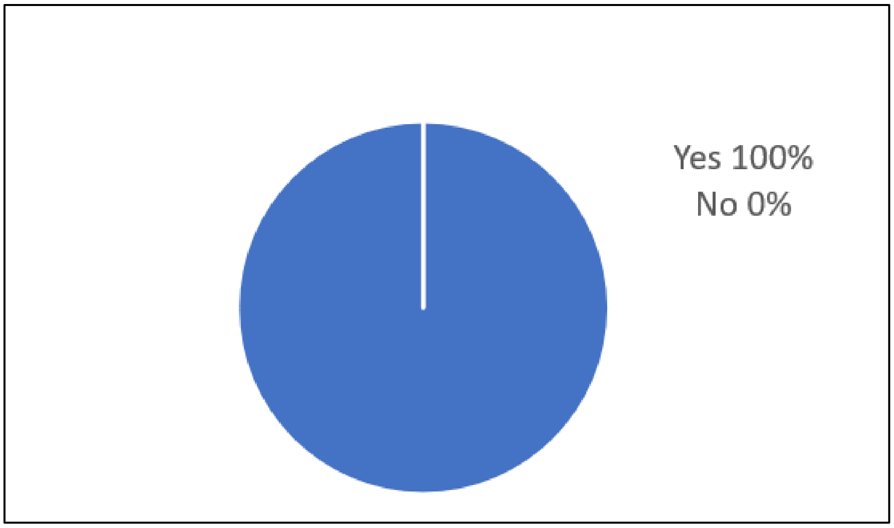

Figure 13: The need for having a system for communicating staff availability

(iii) Focus Group Discussion with Students

To gather requirements from students, we employed focus group discussions. These sessions began with a series of targeted questions, to understand the demographic nature of the respondents and the current ways they use to search for services, facilities, or offices indoors followed by a collection of user stories.

Gender of Respondents

The collected responses from Fig. 14 reveal a gender distribution among the respondents, with 55% male and 45% female.

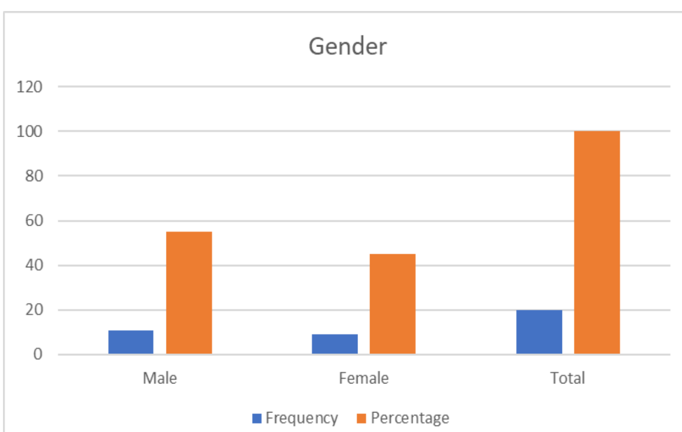

Figure 14: Gender of respondents

Age of Respondents

Figure 15 shows that 35% of respondents fell into the 31-35 age bracket, followed by 25% in the 21-25 range, 20% in the 26-30 category, and 20% in the 36-40 category.

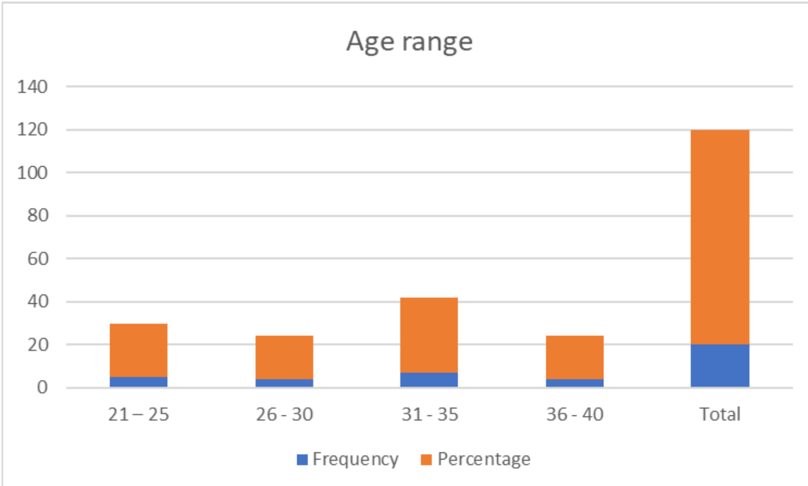

Figure 15: **Age range of respondents**

The Academic Status of Respondents

Figure 16, shows that in terms of academic status, 50% were new students, 35% were continuing students, and 15% were visitors.

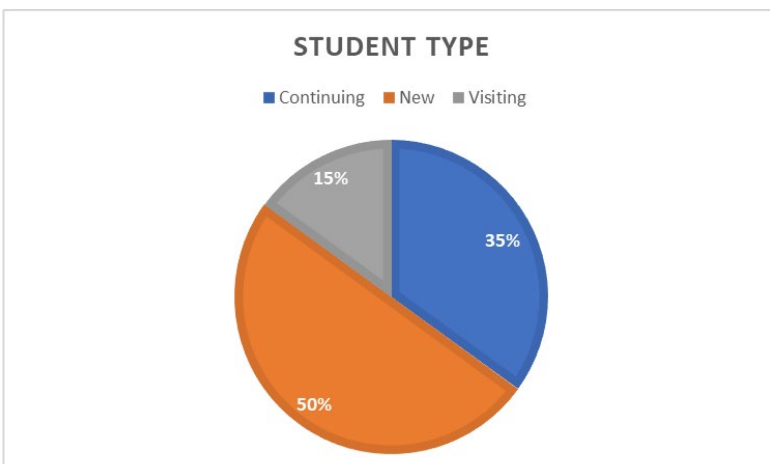

Figure 16: **Academic status of respondents**

Study level of Respondents

Figure 17 shows that the majority, 55%, were pursuing their master's degrees, while 45% were PhD students.

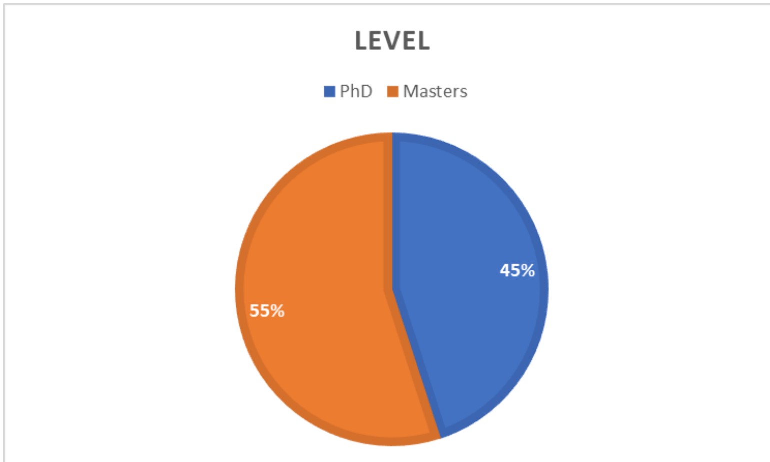

Figure 17: Study level of respondents

School of Respondent

Figure 18 shows that school affiliation varied, with 45% coming from COCSE, 20% each from BUSH and LISBE schools, and 15% from MEWES.

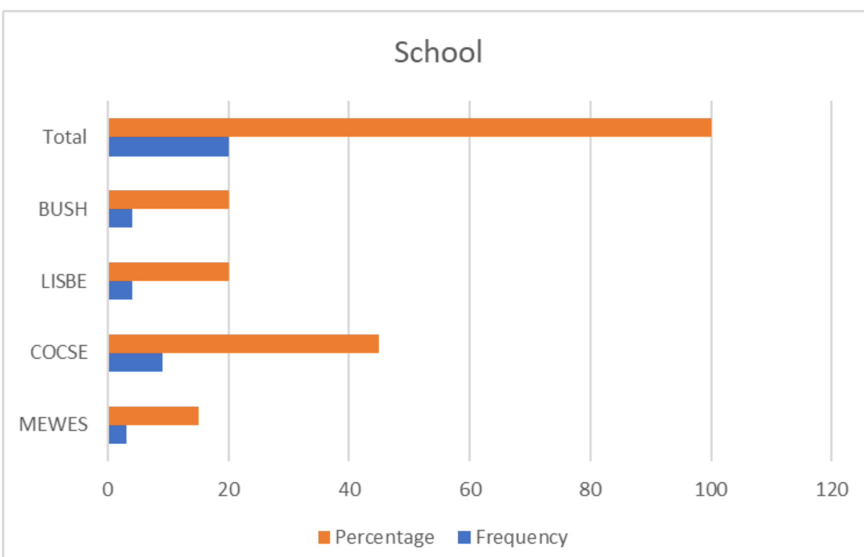

Figure 18: School of respondents

Study year of Respondents

Response regarding their year of study, Fig. 19 shows that 60% were in their first year, with the second and third years each accounting for 20%.

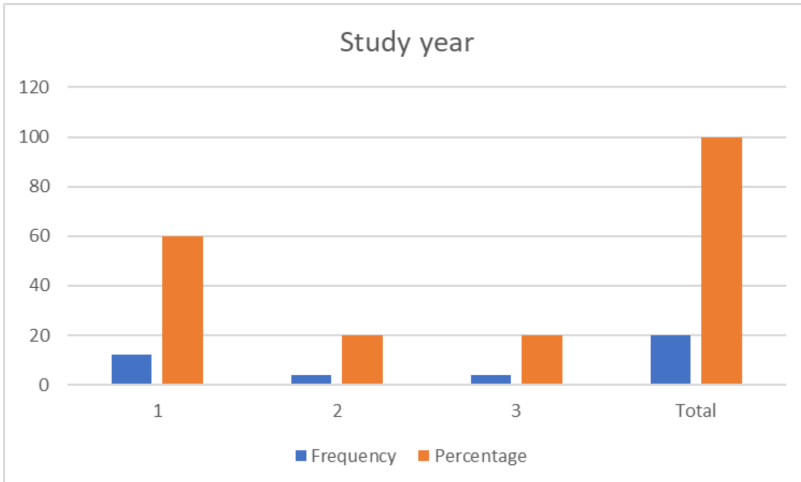

Figure 19: Study year of respondents

4.1.2 Identified Requirements

This section outlines the specific requirements for the proposed indoor navigation system, derived from the interviews with visually impaired individuals, and staff, and focus group discussions with students. These requirements are classified into functional and non-functional categories. The requirements are highlighted below:

(i) User stories for the Augmented Reality Indoor Navigation System (AINS) (Functional requirements)

Functional requirements describe the operations, services, and performance tasks of the system from the user's perspective. Additionally, they specify the functionalities of a software or system that it is capable of performing. The behavior of the system is defined by a functional requirement on how the system receives inputs, processes, and produces the output to the user based on users' specifications (Chung *et al.,* 2000). Functional requirements that were collected from users as user stories for mobile application development and web portal development are presented in this section.

The focus group discussion with students, interviews with visually impaired individuals, and interviews with staff members were instrumental in collecting user stories for developing the proposed indoor navigation application, designed to enhance the indoor experience for both the visually impaired and non-visually impaired. These stories were gathered to identify key features of the proposed system.

The user stories, derived from these interviews and focus group discussions, are systematically presented in Tables 10, 11, and 12, corresponding to the visually impaired, staff, and students, respectively. These user stories were prioritized to create a ranked backlog of user stories. This prioritization was crucial to ensure the most relevant and impactful features were highlighted.

Further, the process included the manual journaling technique to identify different themes of user stories for duplication and overlap. This step was essential to eliminate redundant stories and those representing similar features, thereby streamlining the feature set for the application and ensuring a focused and effective development process.

Table 10: User stories backlog from visually impaired people

SN	Story ID	User story
1	101	As a visually impaired individual, I want to be able to navigate indoor spaces using an AR indoor navigation system so that I can independently move around and explore unfamiliar environments.
2	102	As a user with vision impairment, I want the AR indoor navigation system to provide audio-based directions and descriptions of my surroundings so that I can understand my location and the obstacles or landmarks in my path.
3	103	As a user with vision impairment, I want the AR indoor navigation system to have voice recognition capabilities, so that I can provide verbal commands or ask questions to the system without relying on manual input.
4	104	As a visually impaired individual, I want the AR indoor navigation system to have a wayfinding feature that can guide me to the nearest accessible entrance, elevator, or restroom so that I can navigate the building efficiently and independently.

Table 11: User stories backlog from staff

SN	Story ID	User story
1	201	As a staff, I want to easily update the status of my availability in the office so my visitors can be informed before visiting my office.
2	202	As a staff, I want the system to provide direction toward my office so students can be guided to my office.
3	203	As a staff, I want the system to provide an interface where I can read messages left by my visitors when they do not find me in the office.
4	204	As a staff member, I want the system to be user-friendly and allow me to recover my credentials upon loss.

Table 12: User stories backlog from students

SN	Story ID	User story
1	301	As a student, I want to be able to navigate through the campus buildings using an AR indoor navigation system, so that I can easily find my classrooms, labs, and other facilities.
2	302	As a student, I want the AR indoor navigation system to provide real-time directions and display the shortest and most efficient routes so that I can save time and avoid getting lost.
3	304	As a student, I want the AR indoor navigation system to show additional information about each room or facility such as if staff is in the office or when will they be in the office.
4	305	As a student, I want the AR indoor navigation system to include a search function, allowing me to search for specific rooms, departments, or services within the campus buildings so that I can easily locate them.

(ii) Non-Functional Requirements

In software engineering, a non-functional requirement refers to the description of how the to-be-developed software will perform and do tasks instead of describing what the software will do. This includes performance requirements, software external interface requirements, software design constraints, and software quality attributes and normally they are evaluated subjectively because they are challenging to test (Chung *et al.,* 2000). Table 13 presents non-functional requirements for the AINS system for both web portal and indoor navigation applications.

Table 13: Non-functional requirement for the AINS system

SN	Requirement	Description
1	Usability	The system must be user-friendly, with an intuitive interface that is easily navigable by users with different abilities.
2	Accessibility	The application must comply with accessibility standards, ensuring that it is usable by people with various types notably visual impairments
3	Performance	The system should perform efficiently, with minimal latency in providing navigation instructions and real-time updates and means for availability status updates.
4	Scalability	The system should be able to increase or decrease in performance depending on the demand for extension or adoption.
5	Security and Privacy	The system must ensure the security and privacy of user data
6	Reliability	High reliability is critical, as users will depend on the system for safe navigation in unfamiliar environments and communicating office availability status.

4.1.3 System Design Results

This section presents the design results of the proposed web portal for staff availability status updates and indoor navigation applications.

(i) System Architecture Design

The system's architecture design in Fig. 20 was developed as the result of gathered functional and non-functional requirements. The system architecture presents a comprehensive overview of how various components integrate and interact through data flow. The system comprises two main parts: a web portal designed for staff to update their office availability status and an indoor navigation application. The application is interconnected with several components to augment its functionalities. These include IBM Watson for voice recognition, an RSSI database for Wi-Fi fingerprinting, and SLAM for localization capabilities. Additionally, the system involves user interaction processes. The web portal's architecture utilizes PHP, Bootstrap, CSS, JavaScript, and MySQL for backend development. On the other hand, the application is developed using C#, JSON, and Python.

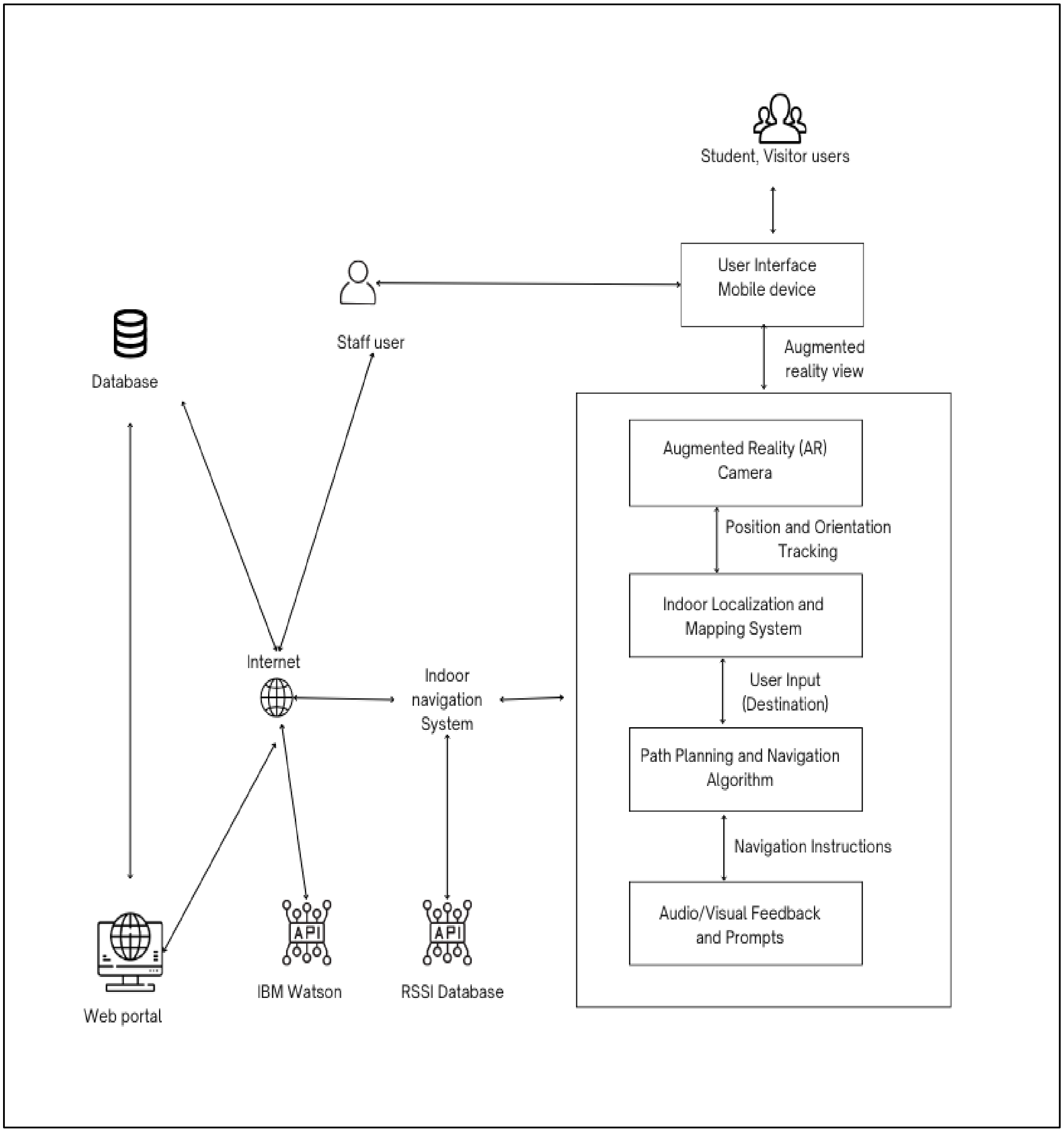

Figure 20: System architecture diagram

(ii) Wireframes for AINS

Low Fidelity Design

Low-fidelity wireframes for both the web portal and application were drawn during the designing process to provide an initial design to the user on how the layout of the system will be. Figure 21 and Fig. 22 show low-fidelity wireframe designs.

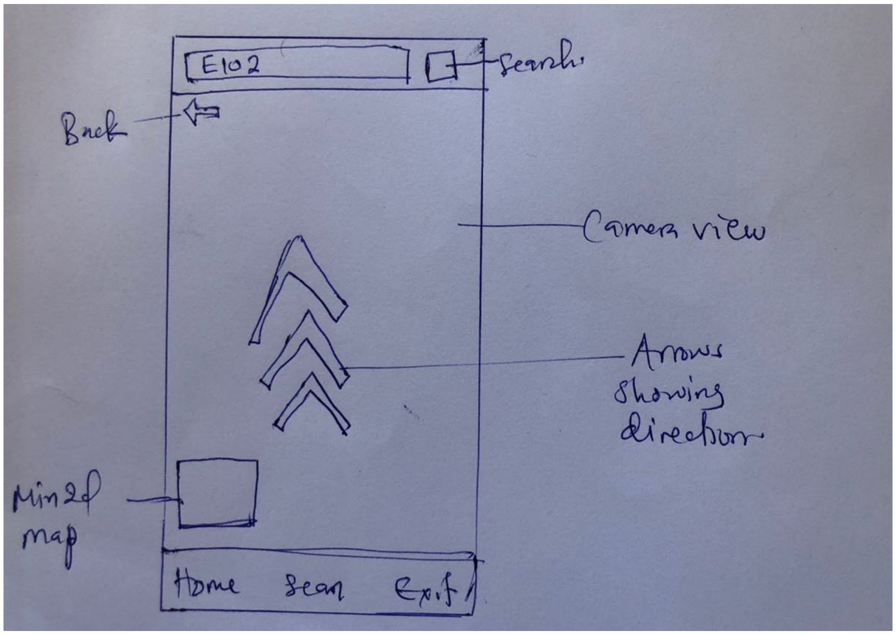

Figure 21: Mobile application wireframe

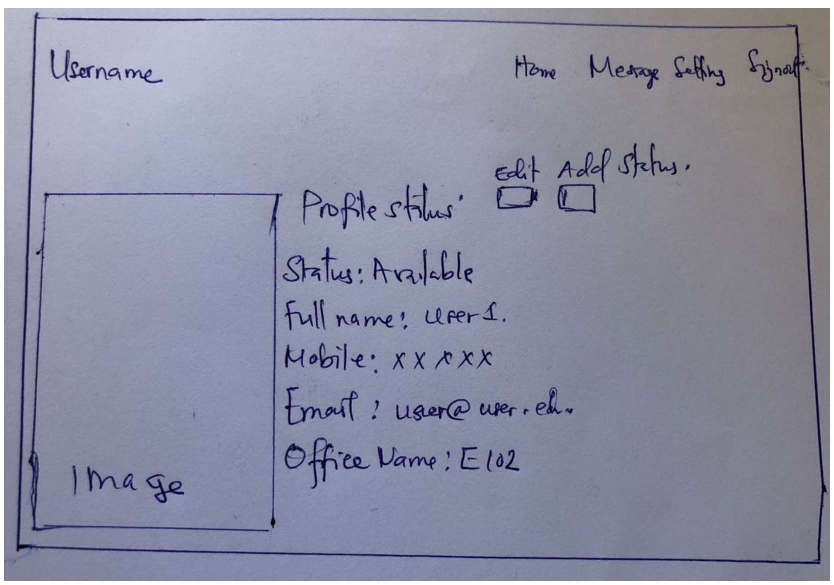

Figure 22: Web portal dashboard wireframe

High Fidelity

The Figma design tool was utilized to create and design high-fidelity wireframes, effectively representing the layout of the proposed system. These wireframes serve as detailed blueprints, illustrating the planned structure and design elements of the system. Specifically, Fig. 23 showcases the layout of the landing page for the AINS web portal, while Fig. 24 depicts the layout of the landing page for the AINS application.

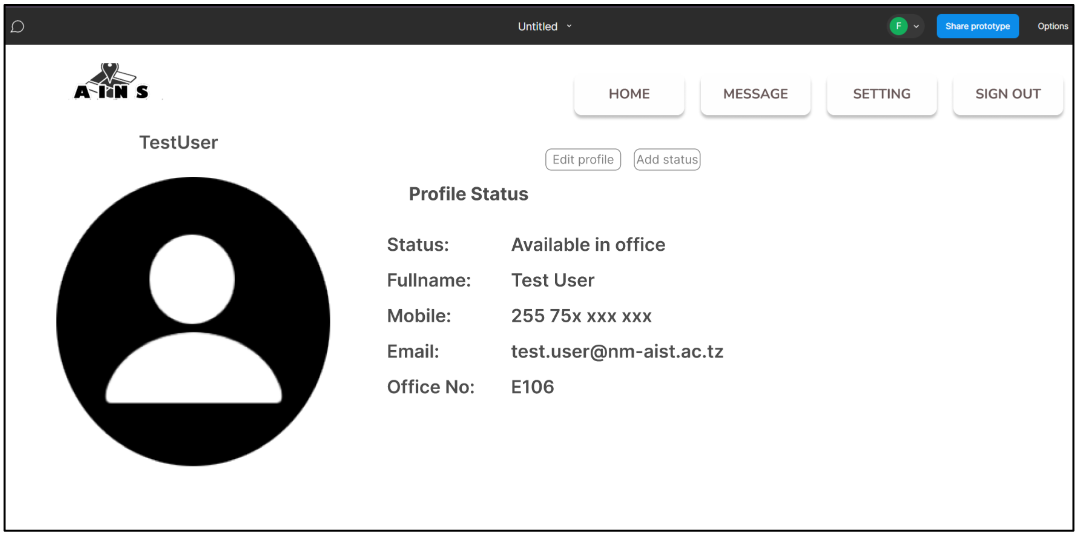

Figure 23: Landing page of AINS web portal in Figma

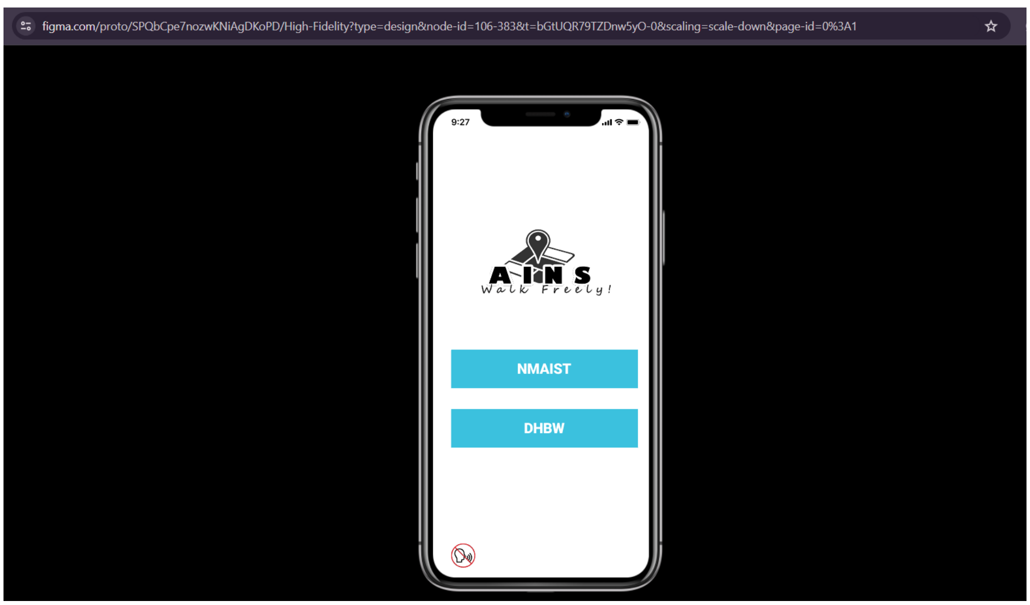

Figure 24: AINS mobile application

(iii) Flowchart Diagram

Figure 25 and 26 demonstrate flowchart diagrams of the AINS application and web portal respectively, the flowchart diagram provides decision points, sequence, or workflow of the system from the start point to the end point of the system during its usage and decision points of the system when the user is using it (Velarde-Camaqui *et al.,* 2023). The dataflows between different steps are denoted using arrows to show the source to the destination of the data.

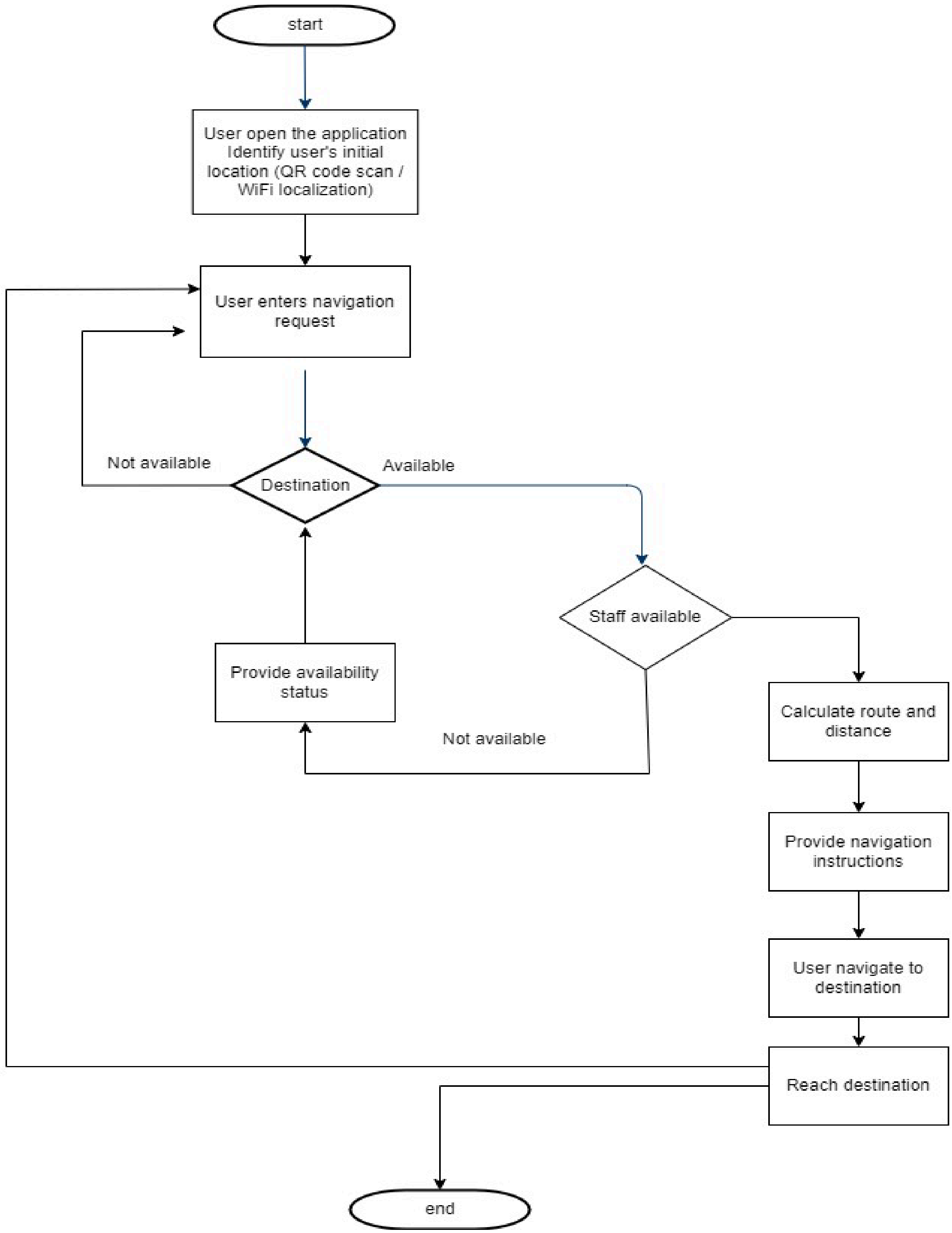

Figure 25: Flowchart diagram for AINS application

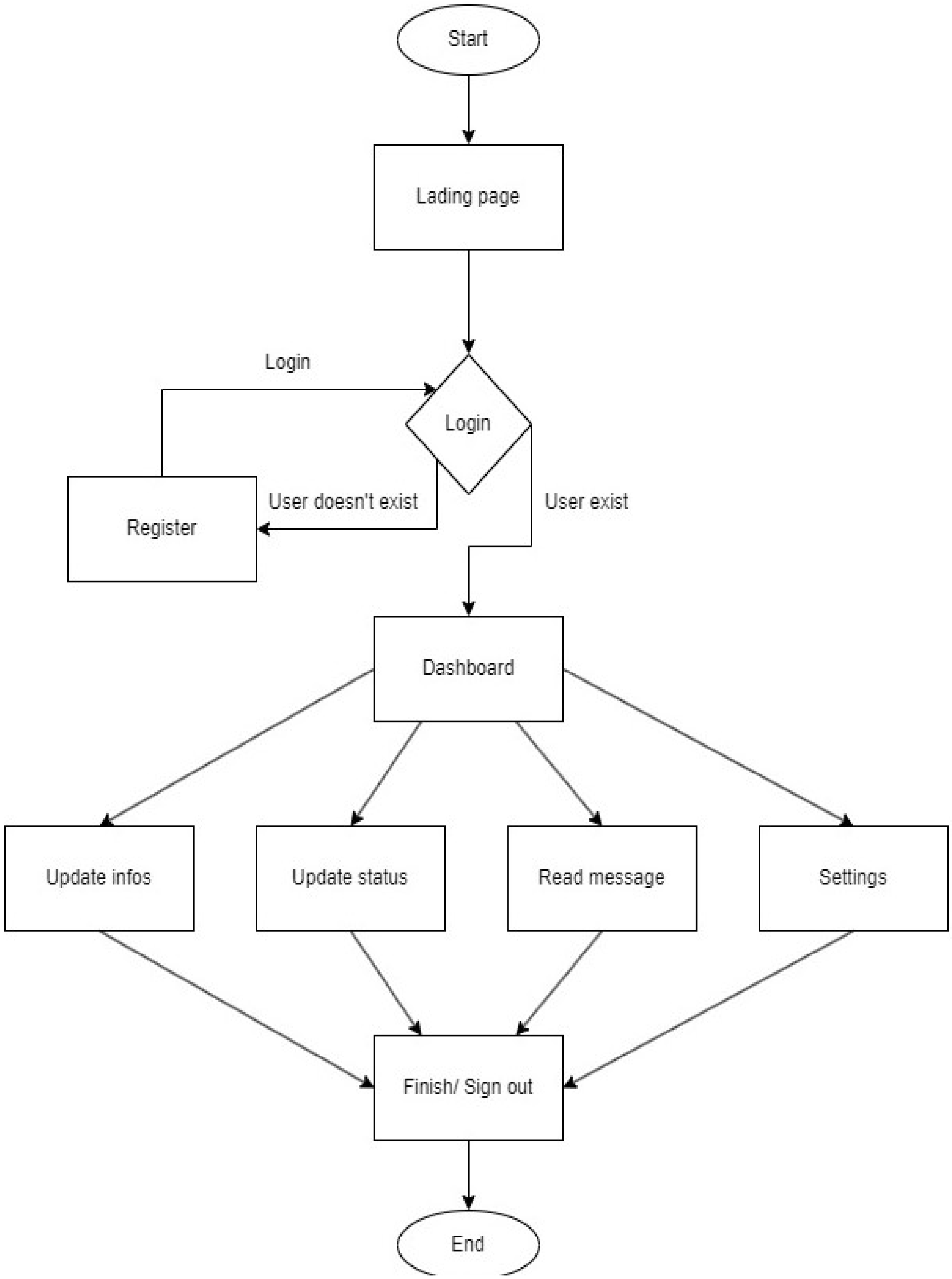

Figure 26: Flowchart diagram for AINS web portal

(iv) Use Case Diagrams

Use case diagrams serve to outline the system's functions and scope, illustrating the interactions between the system and its actors. We have developed use case diagrams to depict the engagement of various actors with both the indoor navigation application and the web portal. Figure 27 and Fig. 28 specifically illustrate the use cases for the AINS web portal and the AINS application, respectively.

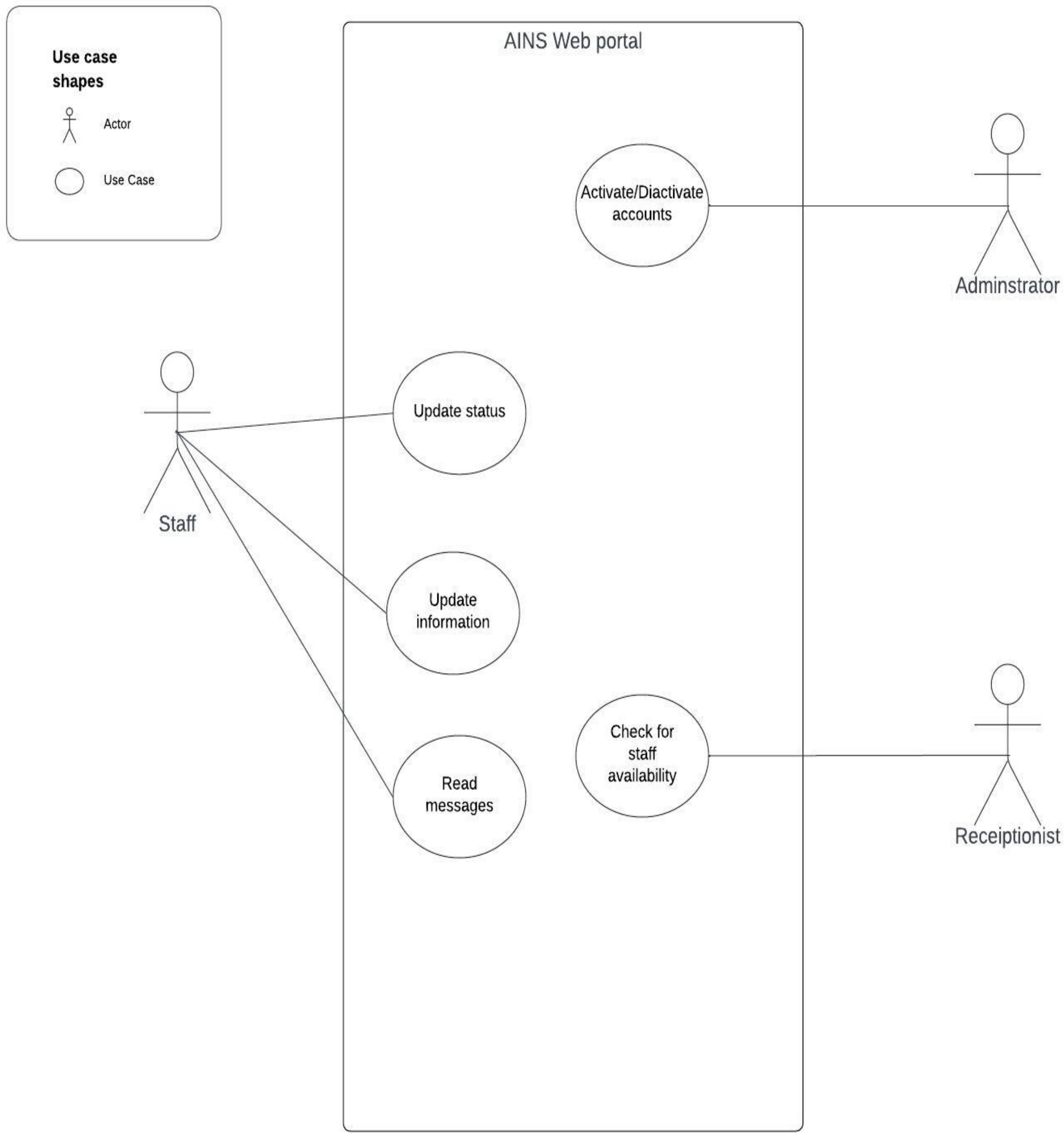

Figure 27: AINS Web portal use case diagram

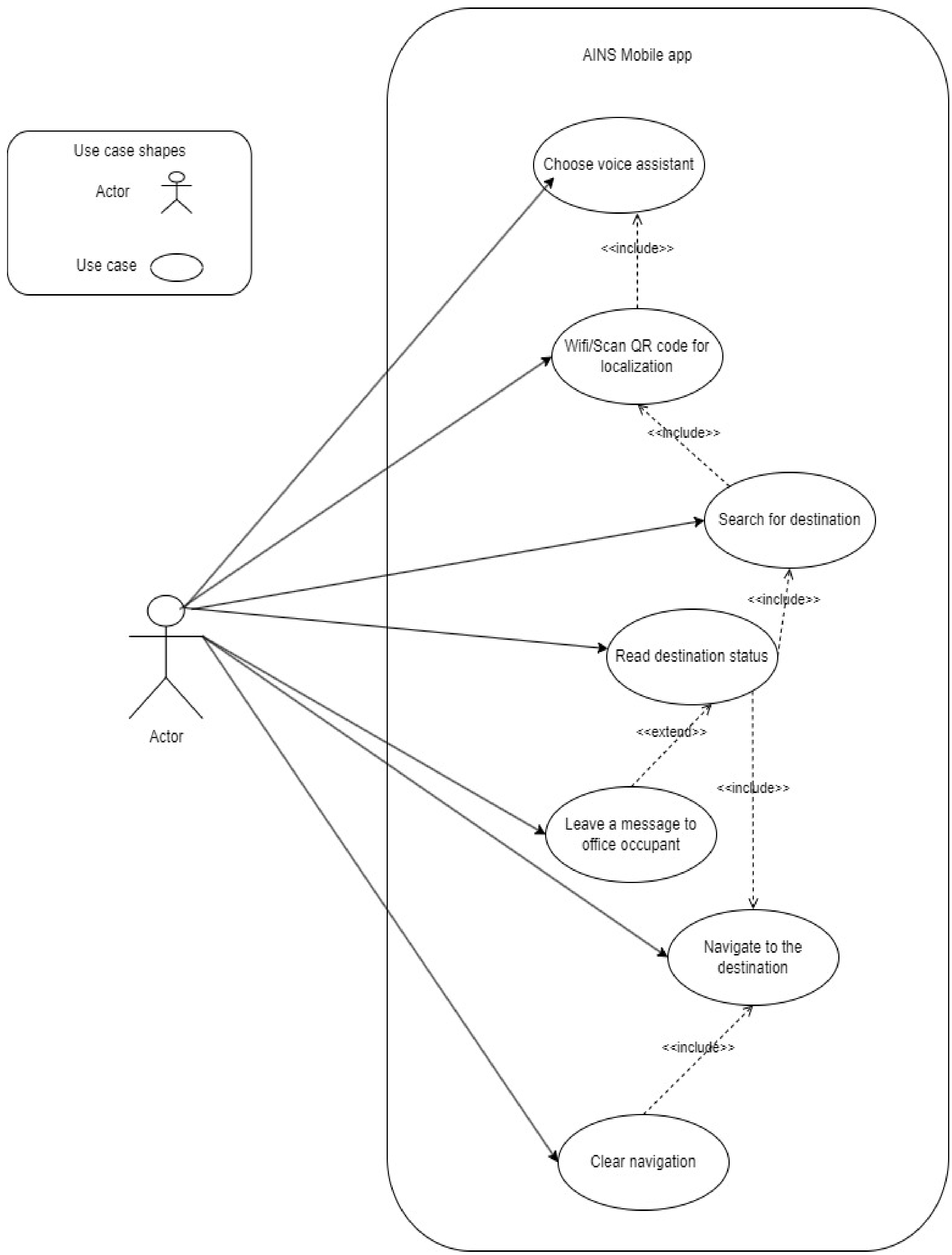

Figure 28: Use case diagram for AINS application

(v) System Data Flow Diagram

Data flow diagrams (DFD) are used normally to depict the functionalities of the developed system. Also referred to as a context diagram which provides a general overview of the system how the data flows between the components and how the system is modeled. Figure 29 presents the DFD diagram of the developed system. The figure depicts four types of users' students, admin, visitors, and staff along with the data that flows to and from the user to the system. The admin user is responsible for room and account management of the web AINS system, visitors and students interact with the system by searching the office, leaving messages, and getting office status and navigation guide from the system. Lastly, staff users interact with the system by performing account settings, updating their availability status, and reading messages left by their visitors,

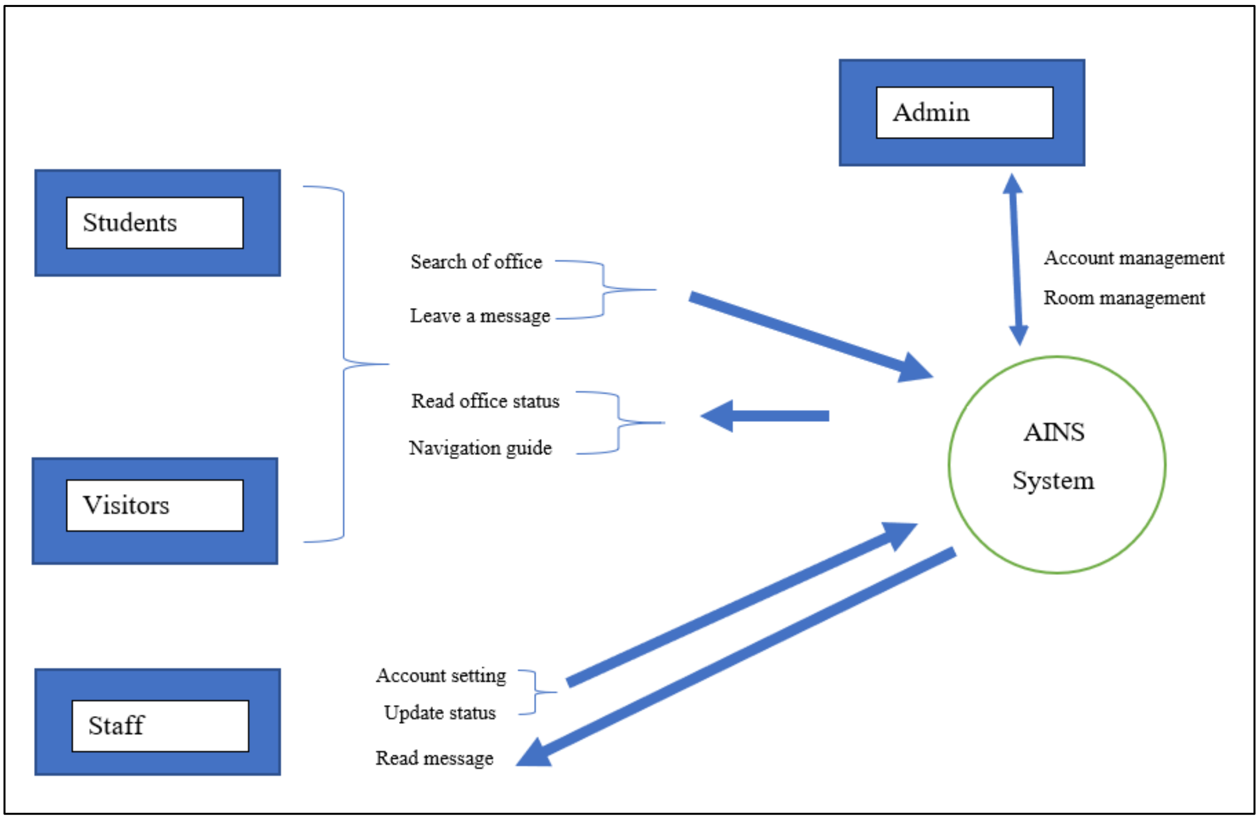

Figure 29: Data flow diagram of the developed system

(vi) Database Design

The database was developed using MySQL database management system which is open-source and provides the environment for the development and designing of the database. The database was created for the staff availability status web portal. The portal has four tables: Users, failed_logins, Targets, and messages. Figure 30 shows the Entity-relationship (ER) diagram of the developed web portal for updating staff availability status.

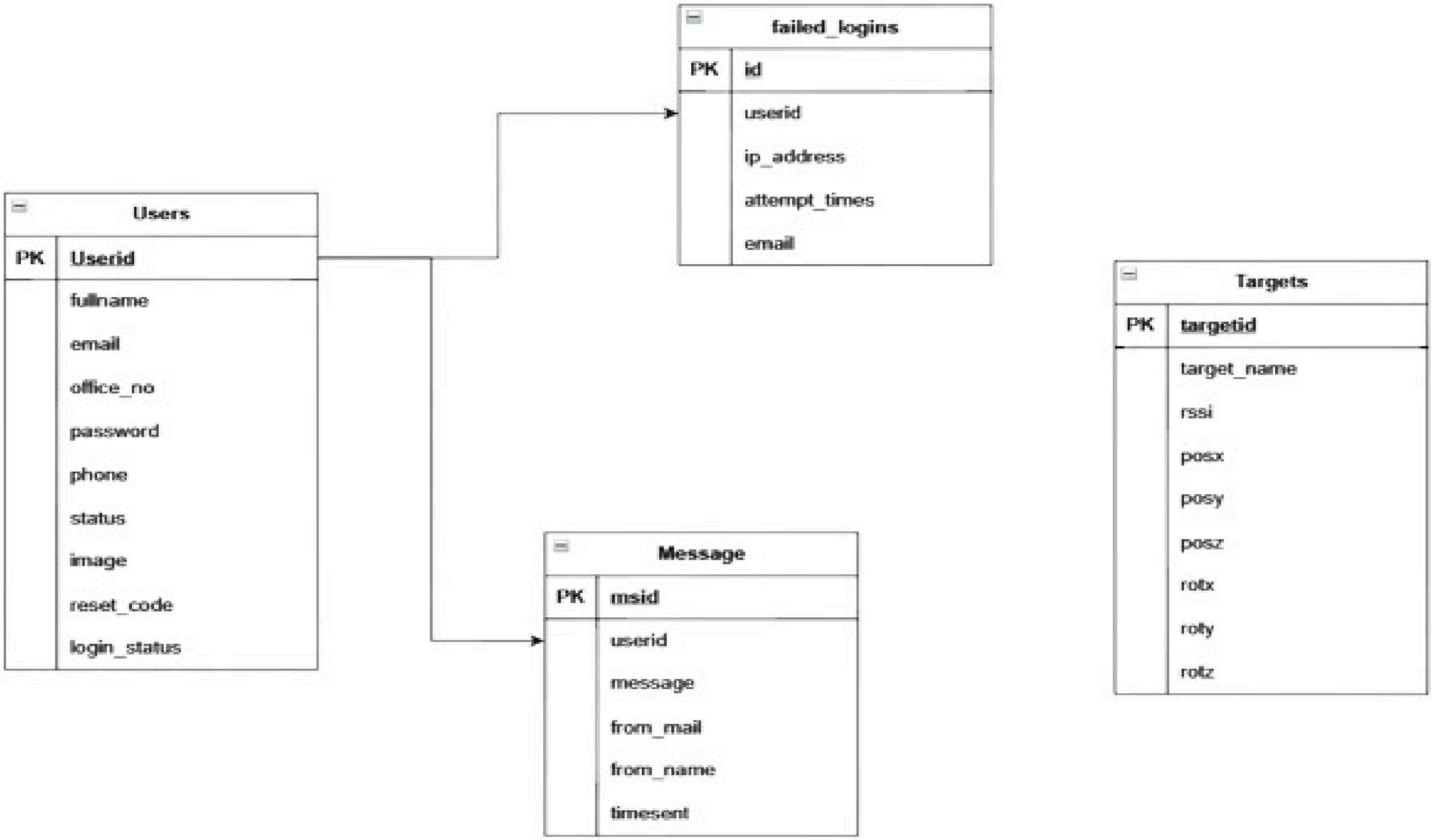

Figure 30: Entity-Relationship (ER) Diagram of the staff web portal

4.1.4 System Development Results

This section showcases snapshots of various interfaces of the developed indoor navigation system to provide insight into the features and details of the system.

(i) Building Maps

Building maps were used in the development of the AR indoor navigation application to be able to augment the direction graphic to the user, calculate the user's initial point, identify the user destination, and calculate the distance between the user's initial location and their destination. Figure 31 and Fig. 32 show the building maps of NM-AIST main building and DHBW main building 6th floor.

Figure 31: A map of the Six-floor DHBW

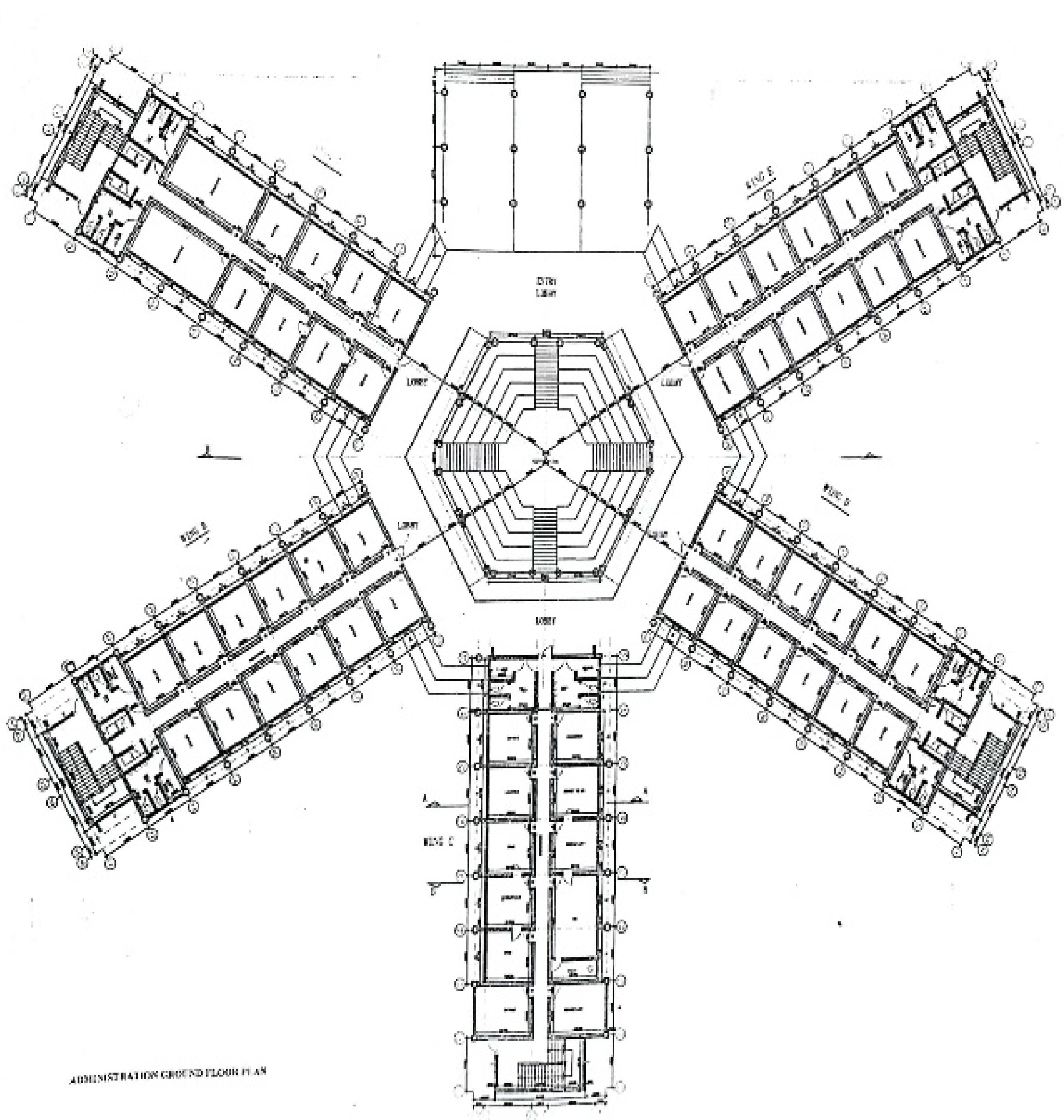

Figure 32: A map of main building of NM-AIST

(ii) Web Portal for AINS

Login Page

The system provides a user-friendly interface that allows a user to access the system from multiple devices. The system is developed using open-source tools that contribute to its responsivity to different browsers. The landing page of the system presented in Fig. 33 provides functionality for staff users to log in if they are already registered to be able to access the system. Additionally, it provides other functionality such as a sign-up link and forget the password for users to be able to recover a lost password.

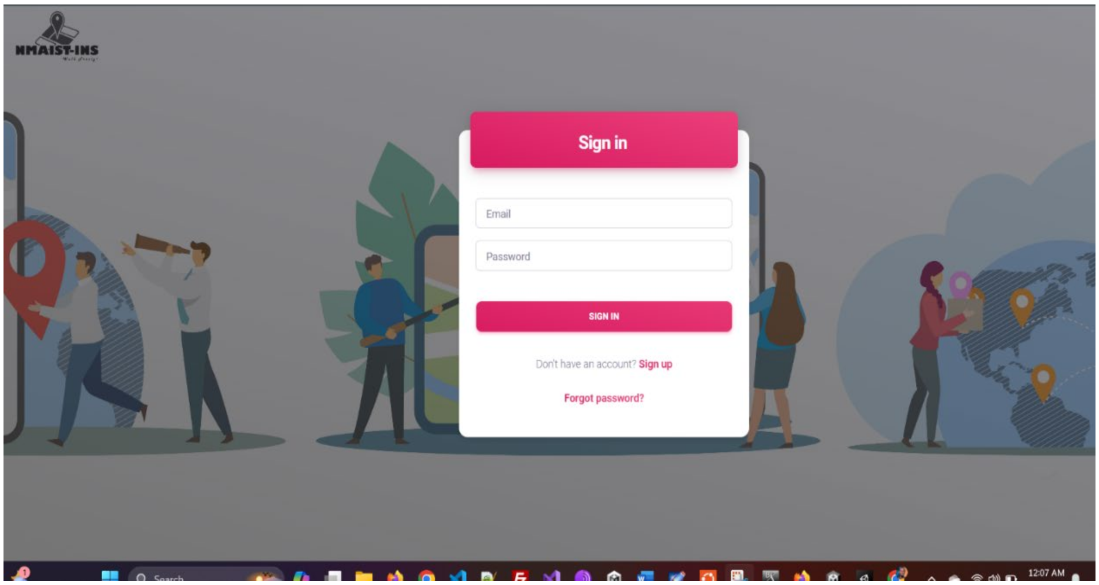

Figure 33: Landing page of AINS web portal

Registration Page

The registration page allows the staff users to register themselves by filling out a signup form with their particulars such as full name, phone number, office name, email, and password. After account creation, they can log in and access the system Fig. 34 presents the interface of the signup page.

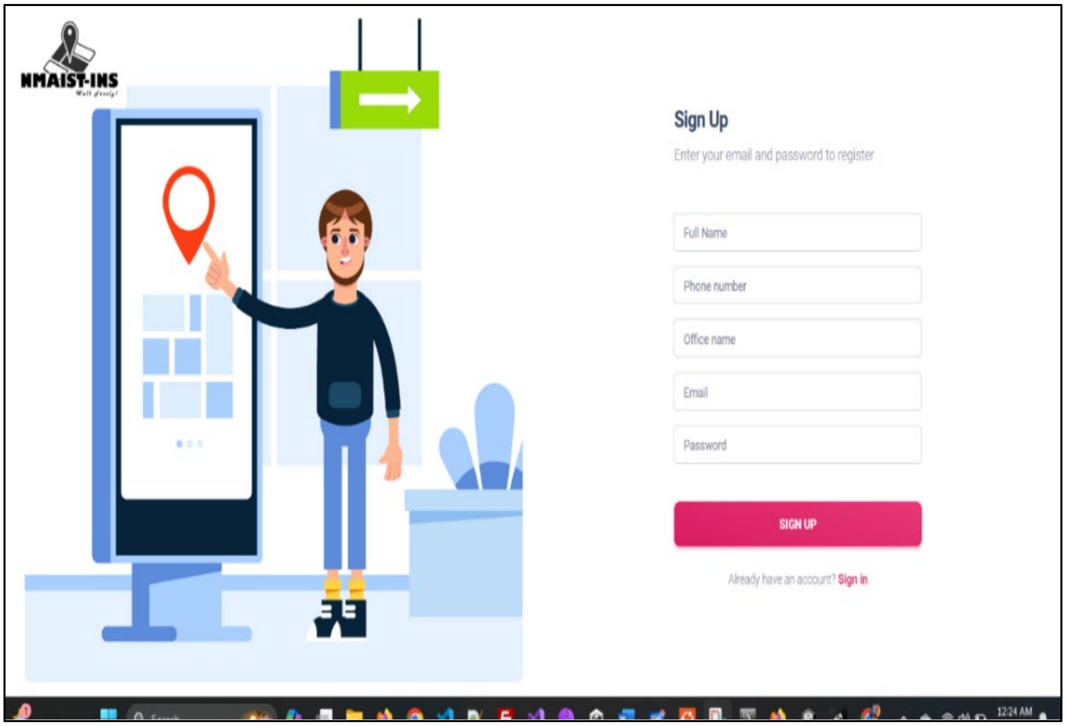

Figure 34: Interface of a form for Sign-up

Forget Password

Whenever the user forgets their login password, they can reset it through the email they used during registration. A code is sent to their email to allow them to proceed with the account recovery process. Figure 35 shows the interface where user can reset their password when it is lost.

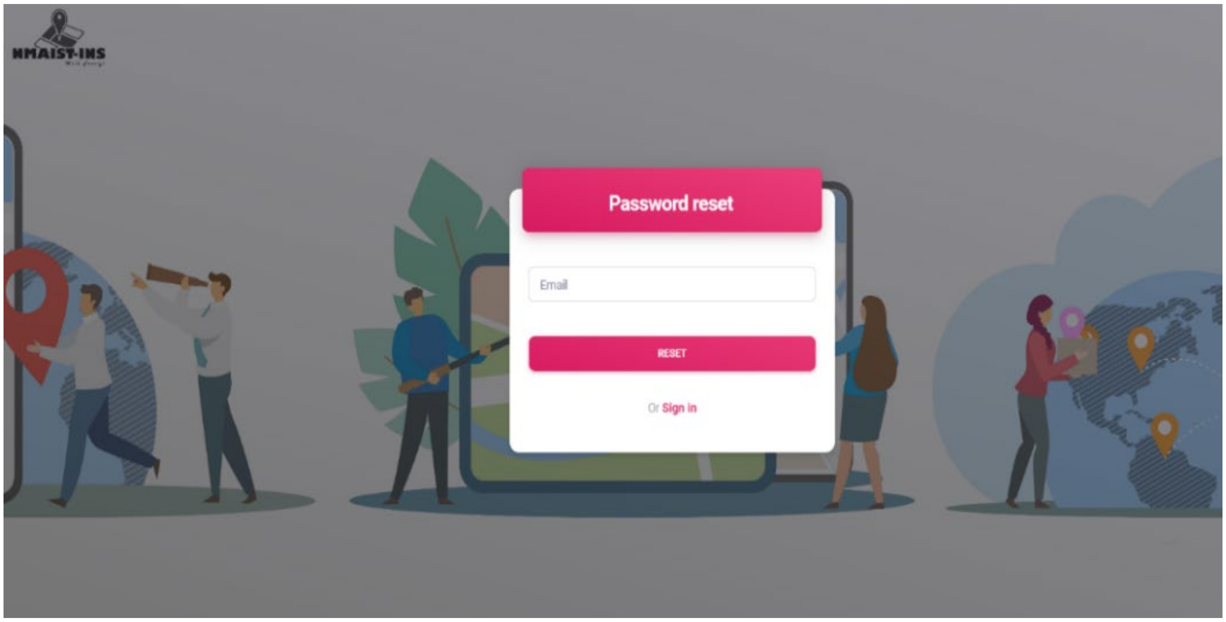

Figure 35: Interface showing a form for password recovery

Dashboard

Once the user login they are welcomed with the dashboard as shown in Fig. 35 which contains several buttons and information relating to their account. They can read the messages left by the visitors who tried to visit their offices, they can change their password, upload profile pictures and update other information relating to their accounts as shown in Fig. 36, and update their availability status that will be displayed when the visitor tries to search their offices for visitation as shown in Fig. 37.

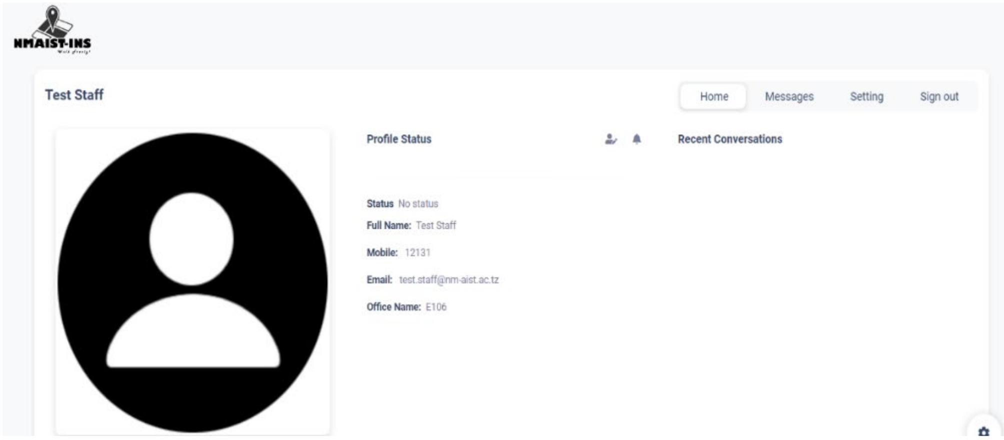

Figure 36: Dashboard interface

Update Profile

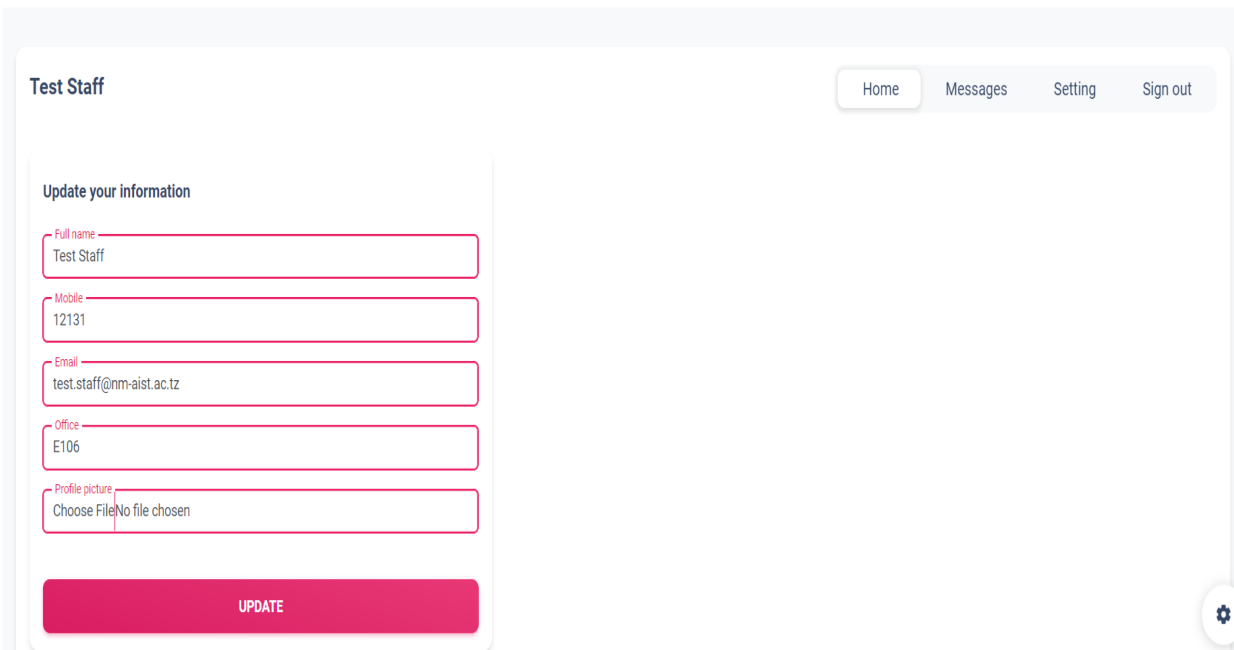

Figure 37: Interface for updating user's information

Update Status

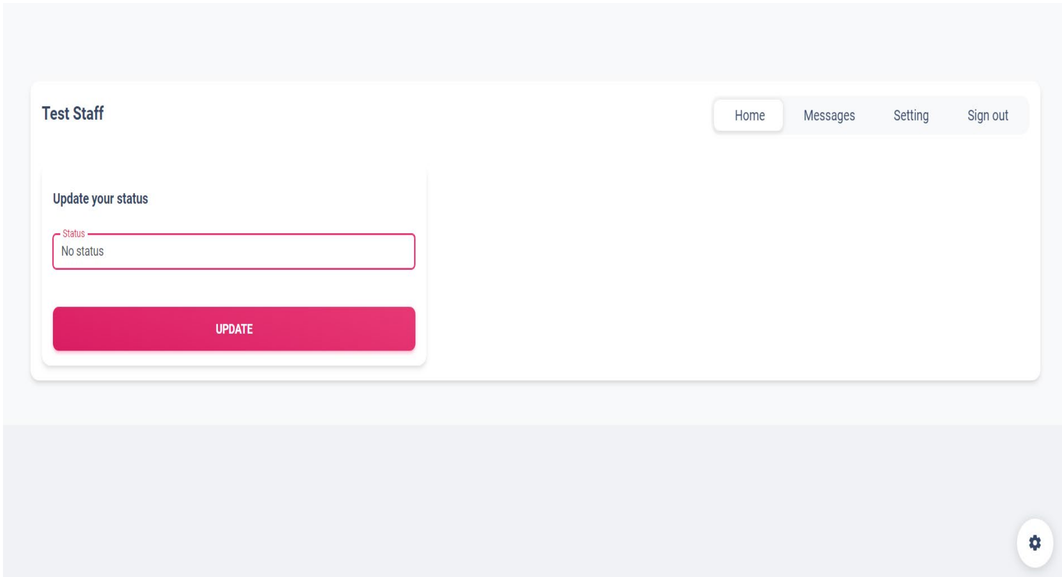

Figure 38: Interface for updating staff's availability status

Web portal Accessibility Evaluation Results

After hosting the website online its accessibility was evaluated using the Achecker web accessibility tool. The results show that the website is accessible and follows the W3S standards for an accessible website and there were no known problems. The results are displayed in Fig. 39.

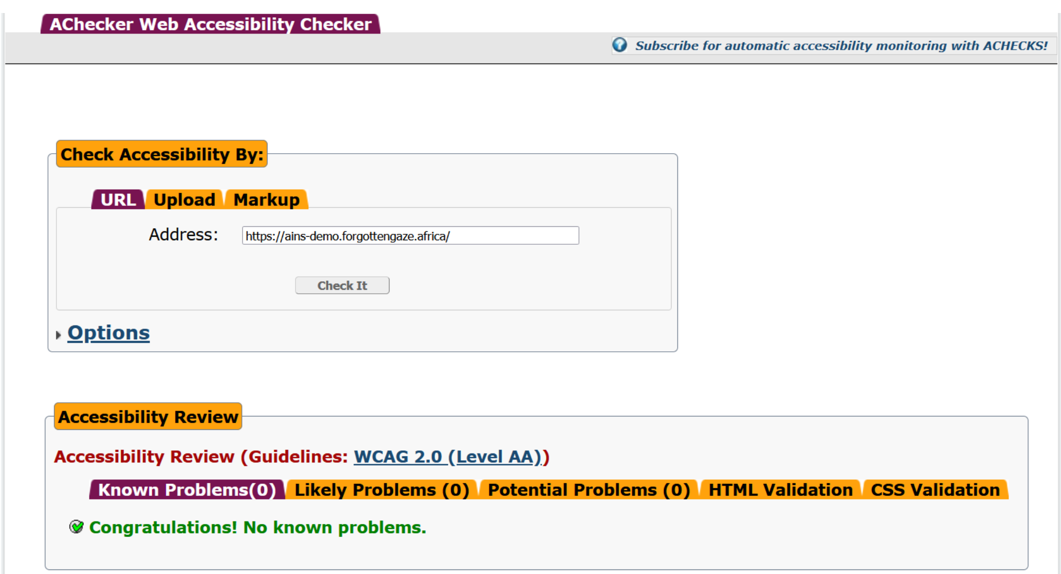

Figure 39: Website accessibility evaluation results

(iii) Wifi Fingerprinting Localization

Model Evaluation

The evaluation process involved a comparative analysis of the two developed models, with a focus on their respective performance metrics. Given the nature of the problem as a non-classification issue, where continuous values are generated, we assessed performance using metrics such as Root Mean Square Error (RMSE), Mean Square Error (MSE), and Mean Absolute Error (MAE). The objective was to determine which model exhibited superior performance. Notably, lower values of RMSE, MSE, and MAE indicate better performance. In our findings, the Random Forest (RF) model achieved an RMSE of 77%, an MSE of 60%, and an MAE of 16.9%, while the K-Nearest Neighbors (KNN) model recorded an RMSE of 83%, an MSE of 69%, and an MAE of 21%. Fig. 40 illustrates the comparative performance of the two models.

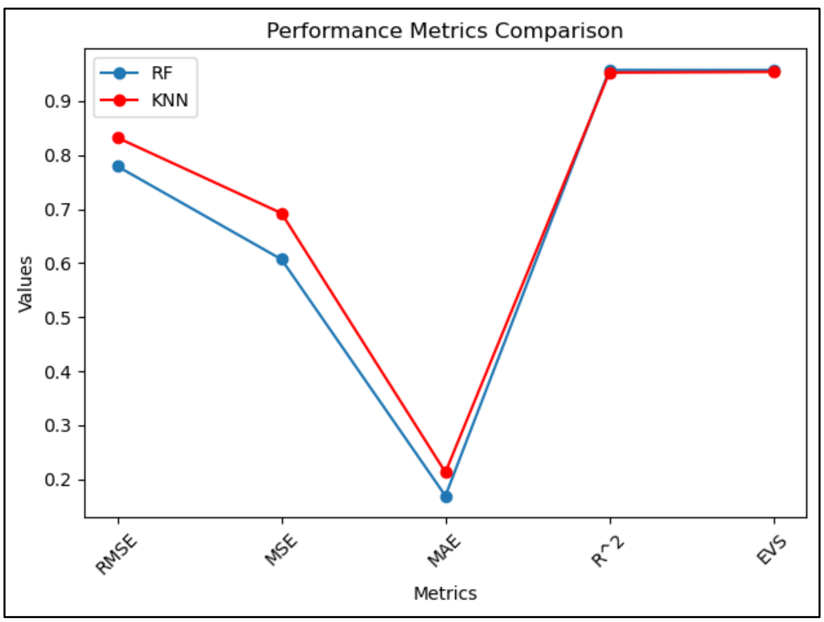

Figure 40: Performance metric comparison between RF and KNN models

Model Deployment

Following the development and performance testing of the model, it was deployed for practical use. The deployment process entailed hosting the model using Heroku hosting services and creating an API to transmit the Received Signal Strength Indicator (RSSI) values of detected

SSIDs for prediction purposes. This API enables the transmission of responses back to the application, facilitating the identification of the initial position using X and Y coordinates.

For the deployment phase, FastAPI was utilized to manage API calls and handle responses. When the application is launched, it detects RSSI signals from nearby Access Points (APs). These signals are then sent to the Model using API, then the model predicts the coordinates of the detected signal and determines the position of the device. Figure 41 shows a sample of API calls to the model using Fast API.

Figure 41: Deployment of the model using Fast API in Heroku servers

(iv) Mobile Application for AINS

The android application was developed using unity and coded in C# that aimed to enhance the indoor navigation experience for visitors and students notably the visually impaired to be able to navigate indoors. Some of the application interfaces are presented in this section. Figure 42 shows the splash screen of the application when it is launched, then followed by the landing page as shown in Fig. 43. The landing page includes options that allow a user to select between the NM-AIST main building and the DHBW main building using both voice commands and button presses.

When the user selects the desired map, they are then directed to another layout interface as shown in Fig. 44 where they can type or use voice commands to specify their destination. Figure 45 shows, an option where a user can leave a message to an office occupant if they are not available in their offices, and soon after clicking done from the reading status the application calculates the distance between the two points and augmented arrows will be generated towards the destination and provide a user with direction to follow towards the destination as shown in Fig. 46.

Figure 42: Splash screen of the application

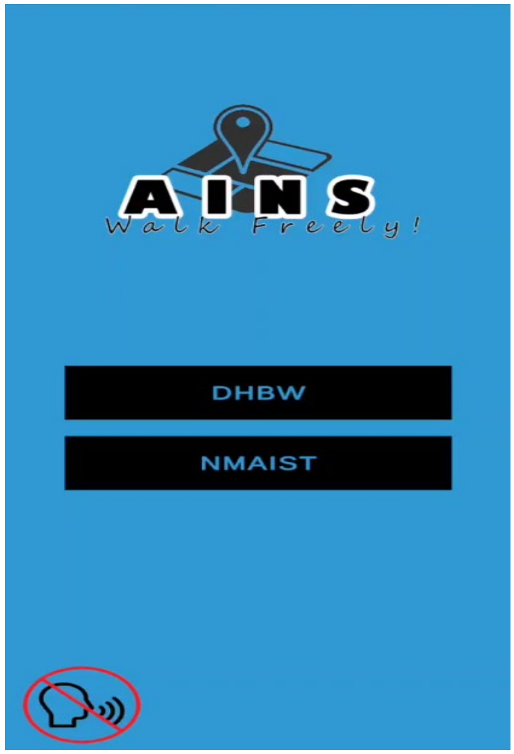

Figure 43: Landing page of the application

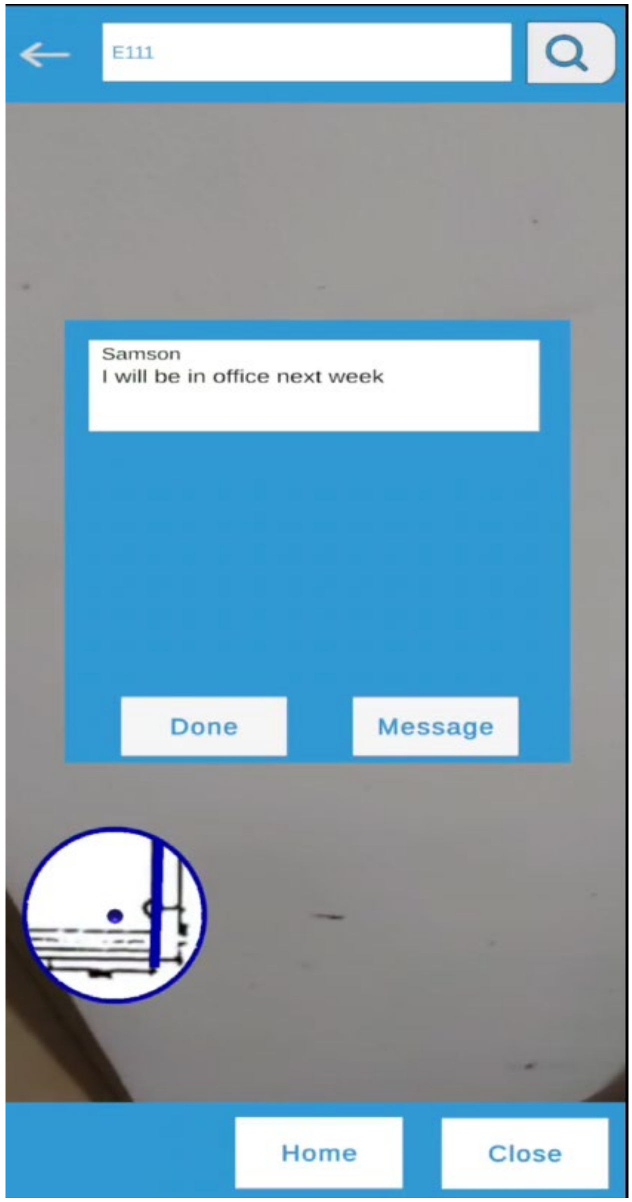

Figure 44: Reading office occupant status from the application

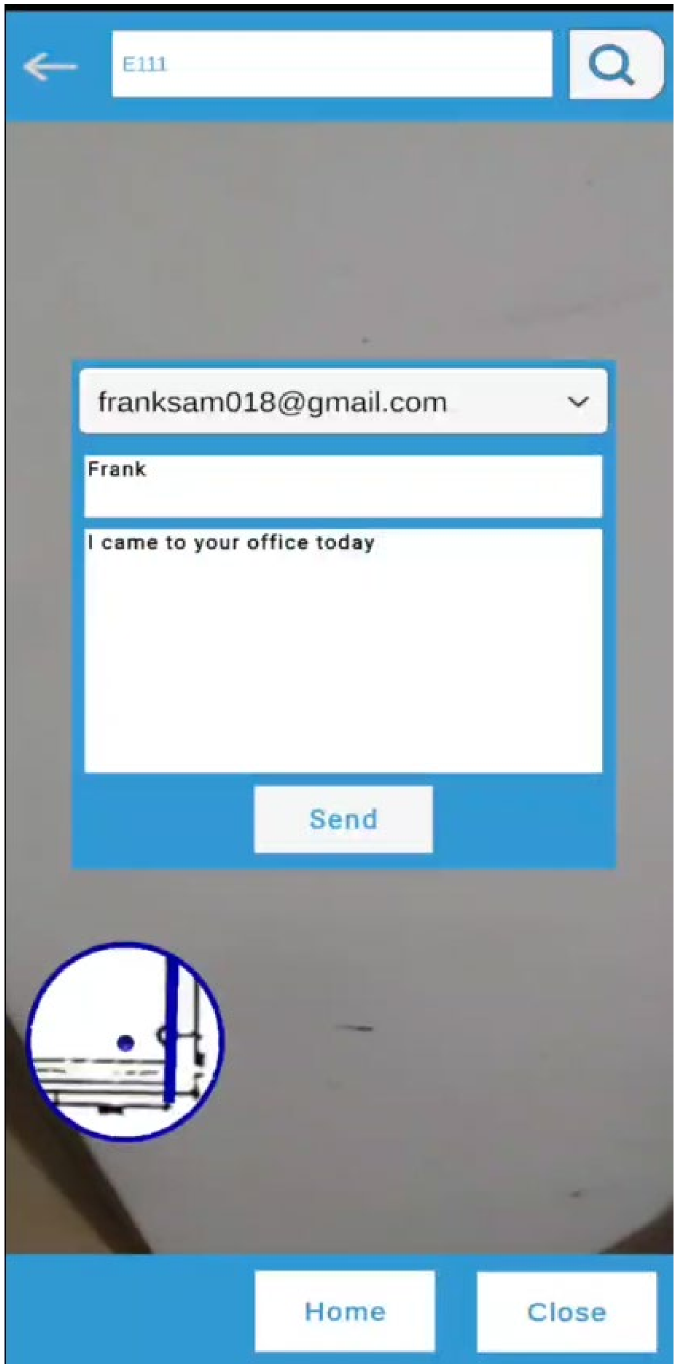

Figure 45: Leaving a message to office occupant from the application

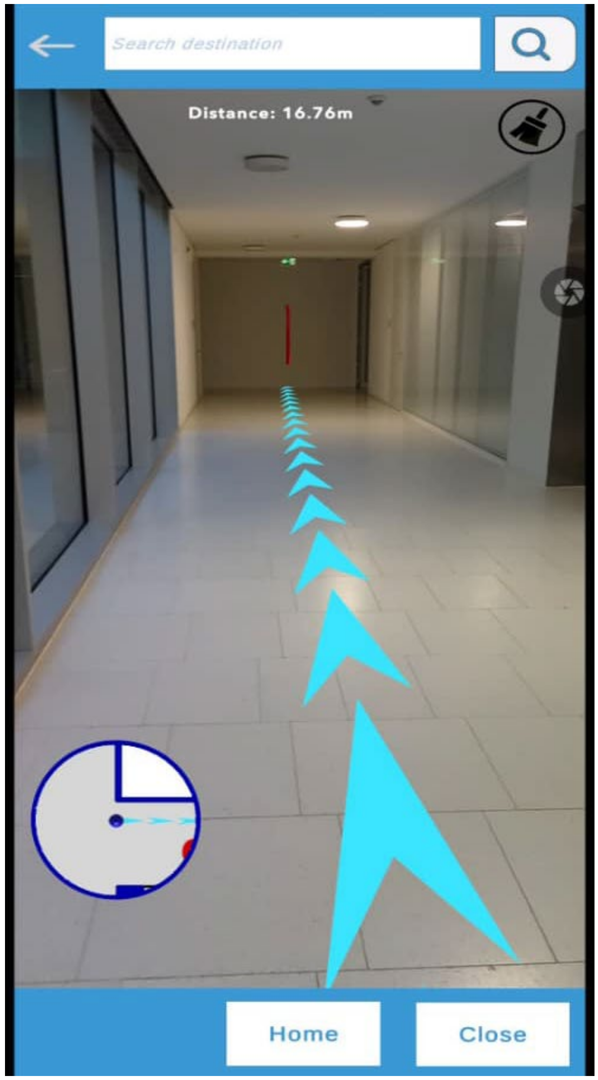

Figure 46: Augmented arrows showing direction

4.1.5 System Testing

System testing encompasses activities including review, inspection, and walkthroughs. These tests were conducted to ensure the system's functionality aligns with the established functional requirements. Table 14 and Table 15 show the test results for the AINS mobile application and AINS web portal respectively.

(i) Indoor Navigation Application Testing

Table 14: The AINS mobile application test results

SN	Requirement	Description	Testing Score
1	QR code scan /Wifi fingerprinting	User should be able to scan a QR code or use WiFi for the application to identify their initial location	√
2	Searching destination	Users should be able to search for their intended destination using the search field in the application	√
3	Reading availability status	Users should be able to read the status left by office occupants	√
4	Leave a message to the staff	Users should be able to leave a message for the office occupants	√
5	Seeing navigation guidance	Users should be able to see augmented arrows showing navigation to their destination	√
6	Seeing the distance to their destination	Users should be able to see the remaining distance or the distance from their initial point to their destination	√
7	Clear navigation	Users should be able to clear their navigation and start afresh.	√

(ii) Staff status availability update testing

Table 15: The AINS web portal testing results

SN	Requirement	Description	Testing Score
1	Login	Registered users should be able to log in to the system using their username and password	√
2	registration	New users should be able to register before using the system	√
3	Update information	Registered users should be able to update their information in the system	√
4	Update Status	Registered users should be able to update their availability status in the system	√
5	Read messages	Registered users should be able to read the messages left by their visitors	√
6	Recover account	Upon forgetting login credentials (password) users should be able to recover their account using their registered emails	√

4.1.6 System Validation

System validation is the process of showing that the developed system meets its system requirements or the requirements gathered from the users. The aim is to make sure that the outputs produced are compliant with its inputs. The developed system was validated by performing user testing to ascertain whether its functionality and user requirements were adequately met. The results of the validation process are provided below:

(i) Indoor Navigation Application (AINS) at NM-AIST

During the validation of the application, five respondents participated in the validation of the AINS mobile application to test its functionalities. The results and validation scores are highlighted in this section.

Consent to Participate in the Validation

Figure 47 shows the response to participate in the validation process where 100% of the majority responded yes to participate.

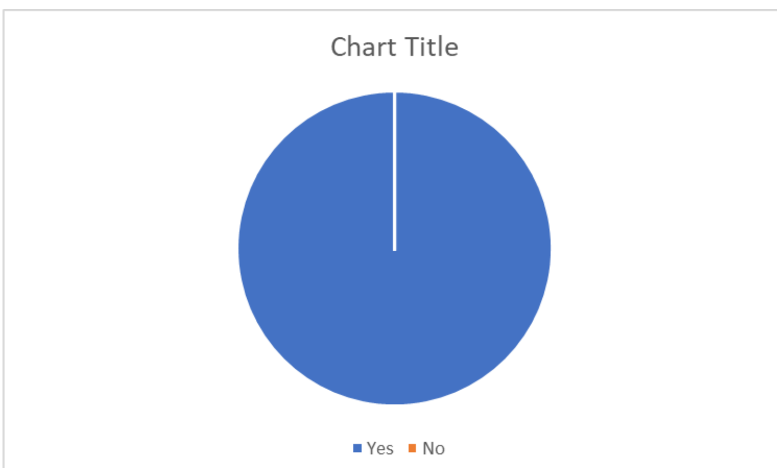

Figure 47: Consent to participate in validation

Gender of Respondents

Results show that 60% of the respondents were male and 40% female. Table 16 shows the results of gender distribution.

Table 16: Gender distribution of respondents

SN	Gender	Frequency	Percentage %
1	Male	3	60
2	Female	2	40
3	Total	5	100

User type and education level

Table 17 shows the results regarding the user type of the respondents and their educational level. The result shows that 80% of respondents were students and 20% were visitors. concerning educational level 60% were master's students 20 % were PhD. students and 20% were others.

Table 17: User type and educational level

Demographic characteristic	Frequency	Percentage %
User type		
Student	4	80
Visitor	1	20
Total	**5**	**100**
Educational level		
Masters	3	60
PhD	1	20
Others	1	20
Total	**5**	**100**

Visual status of the Respondents

Figure 48 shows the visual status of the respondents where 80% of the respondents were non-visually impaired and 20% of the respondents were visually impaired.

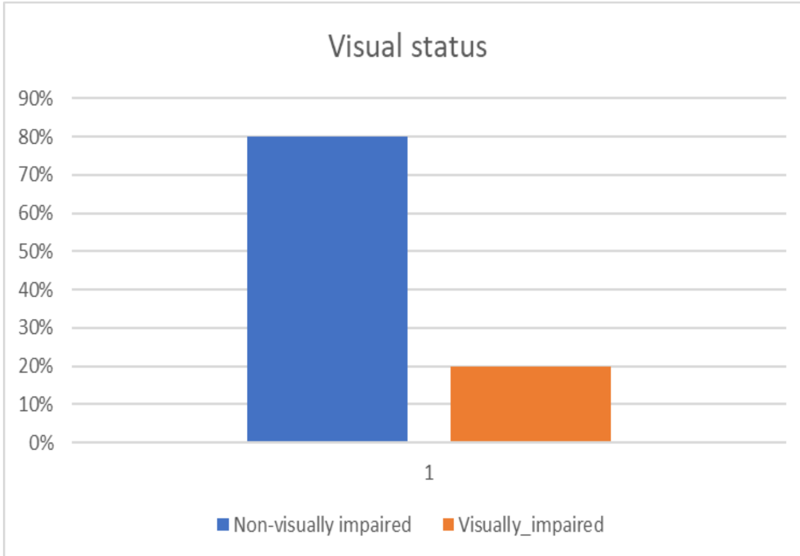

Figure 48: Visual status of respondents

(ii) Functional Requirement Validation

Figure 49 displays the results from the validation of functional requirements, affirming the effectiveness of the application's key functionalities: locating facilities, providing directions, displaying staff availability status, and time-saving during navigation. The validation responses were overwhelmingly positive, with 100% of participants affirming the utility of each functionality. Specifically, for locating facilities, giving directions, viewing staff availability status, and saving time during navigation, every respondent indicated a 'yes' response, demonstrating unanimous approval of these features.

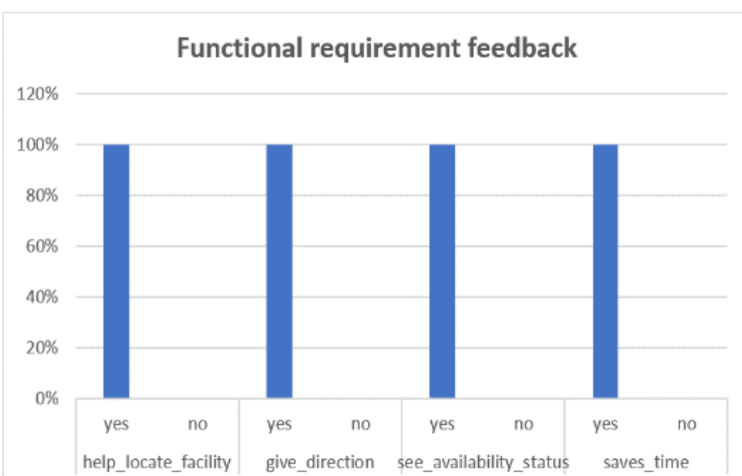

Figure 49: Functional requirement validation results

(iii) Non-functional Validation Results

Figure 50 shows the validation for non-functional requirements. Where user-friendly response scored 100% Yes, effective scored 100% yes, efficient scored 80% yes and 20% no, useful scored 100% yes, stable scored 100% yes accurate scored 80% yes and 20% no, secured scored 100% yes, and reliable scored 100% yes.

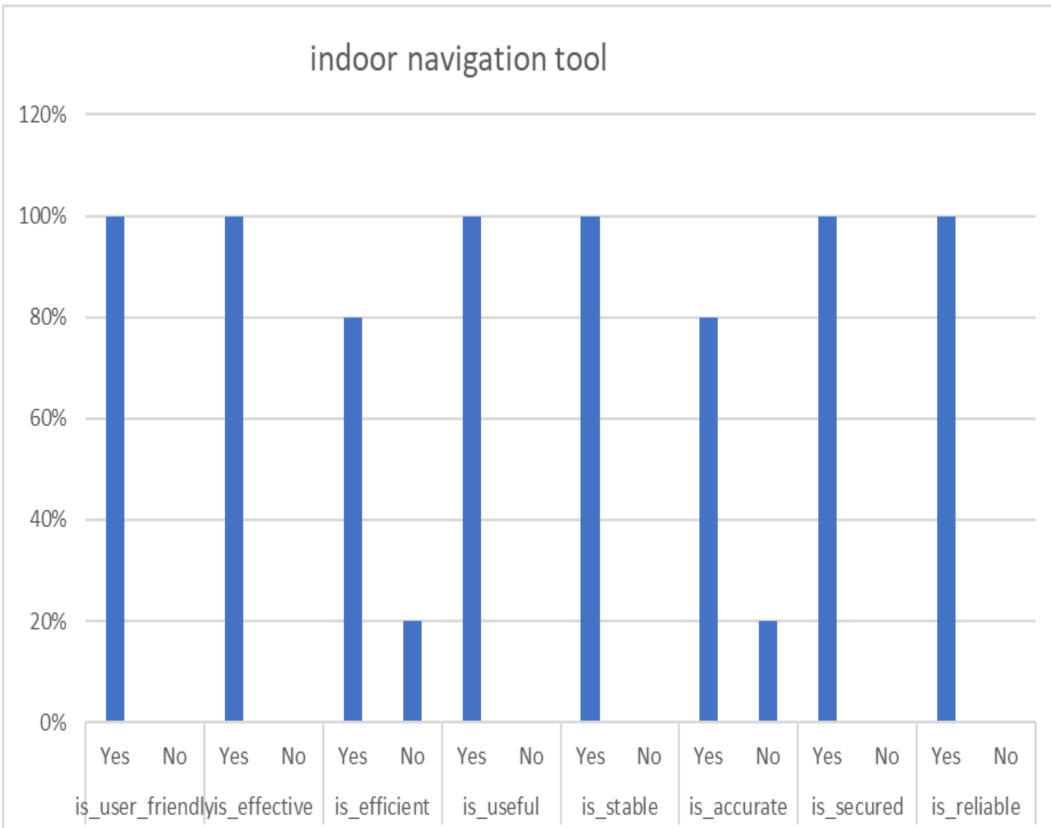

Figure 50: Validation results for the non-functional requirement of AINS mobile application

(iv) Usability Test at DHBW

A workshop on usability testing was conducted at DHBW to validate the indoor navigation too. 18 participants participated in the workshop and tested the usability of the application. Different questions were set to test the usability of the application. The results of the usability testing are presented in this section.

The age Range of the Participants

This question was asked to understand the demographic nature of the participants of the workshop. 18 responded to the question, Fig. 51 shows that 94.4% of the respondents were from the age group of 18 – 24 while 5.6% were from the age group of 25 – 34.

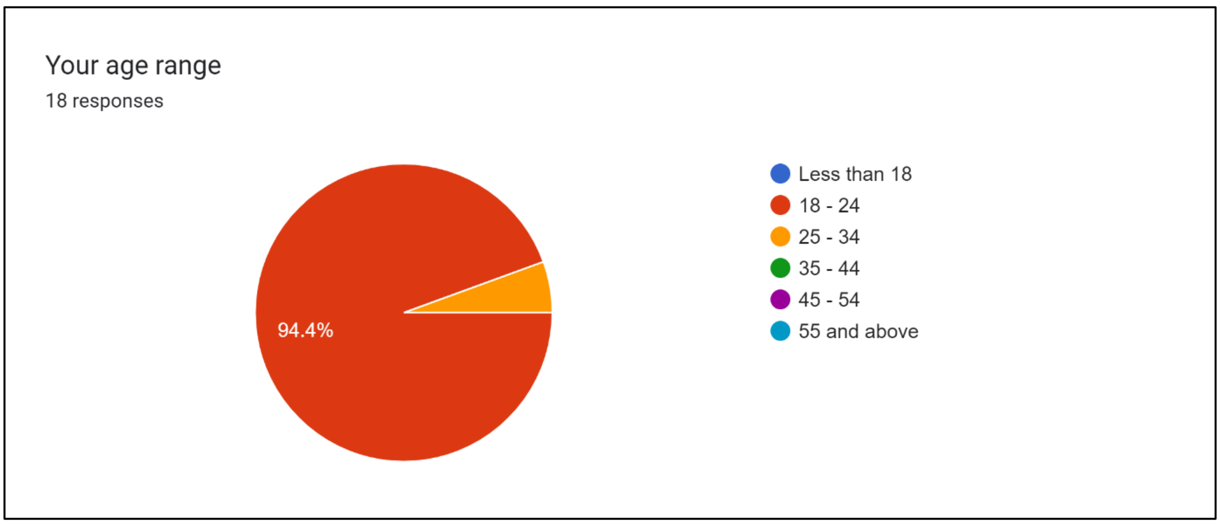

Figure 51: Age of participants

Gender of participants

The gender demographic of the 18 participants of the workshop was 56% male, 39% female, and 5% others as shown in Table 18.

Table 18: Gender distribution of the participants

Gender	Frequency	Percentage %
Female	7	39
Male	10	56
Others	1	5

Have you Used the AR Navigation Application Before?

This question was set to understand the user's knowledge of AR indoor navigation. As presented in Fig. 52, 83.3% of the participants responded NO to the question showing they never used and 16.7% of the respondents responded YES to the question showing they had used AR navigation applications before.

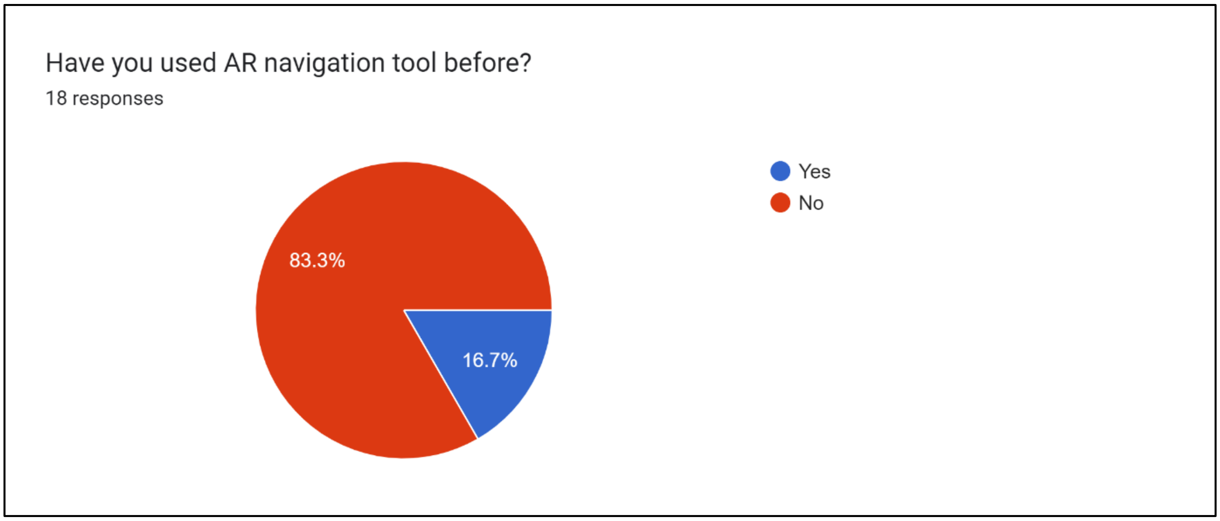

Figure 52: Have you used an AR navigation application before?

How do You Consider the Easiness of Using an Indoor AR Navigation Application?

This question was set to assess the easiness of using the indoor navigation application. As presented in Fig. 53, 50% found it easy to use the application, 22.2% found it to be very easy, 22.2% found it to be normal and 5.6% found it to be difficult to use.

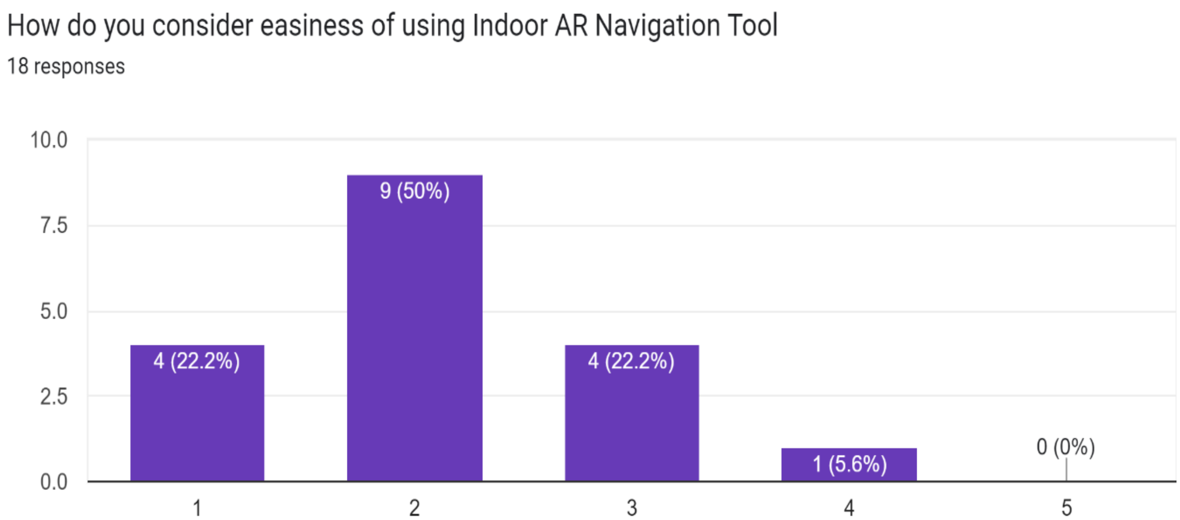

Figure 53: How do you consider easiness of using an indoor navigation application?

What did you like most about the Indoor AR Navigation Application?

This question was set to identify what features the participants found to be more interesting while using the indoor navigation application. Eight of the participants responded to this question and the response to the question is presented in Table 19.

Table 19: Liked features in indoor navigation application.

SN	Response number	Response
1	1	Helps at new places
2	2	The simplicity of operation with the QR code
3	3	The mini-map
4	4	the idea of using it for safety reasons (in case of fire e.g.)
5	5	Easy to find rooms, if you don't know the building
6	6	Very big potential and the idea of the App
7	7	The ease of use
8	8	Very useful for visiting new and complex places

Mention any Challenges that you Faced when Authoring using the Indoor AR Navigation Application

The question was set to identify any observable challenge while using the indoor navigation application. 5 of the respondent's respondents to this question and the responses are presented in Table 20.

Table 20: Challenge while using an indoor navigation application

SN	Response number	Response
1	1	To calibrate the starting point
2	2	The right Starting point
3	3	Correct calibration
4	4	There were no challenges
5	5	Knowing where the starting point is

(v) Staff Web Portal Validation

The AINS web portal was validated for checking the functional and non-functional requirements of the systems. Five users were recruited to validate the system. The results of the validation process are presented in this section.

Demographic results

Results show that 60% of respondents were male and 40% of respondents were female. Table 21 shows the gender distribution.

Table 21: Gender of the respondents

SN	Gender	Frequency	Percentage %
1	Male	3	60
2	Female	2	40
3	**Total**	**5**	**100**

School of Respondents

Table 22 shows that 60% of respondents are from COCSE, 20% of respondents are from BUSH and 20% of respondents are from MEWES.

Table 22: School of the respondents

SN	School name	Frequency	Percentage %
1	COCSE	3	60
2	BUSH	1	20
3	MEWES	1	20
4	**Total**	**5**	**100**

(vi) Functional Requirement Validation

Figure 54 shows the validation results of the AINS web portal where functionalities such as know who visited me, update availability status, update information, and recover password were validated and they scored 100%.

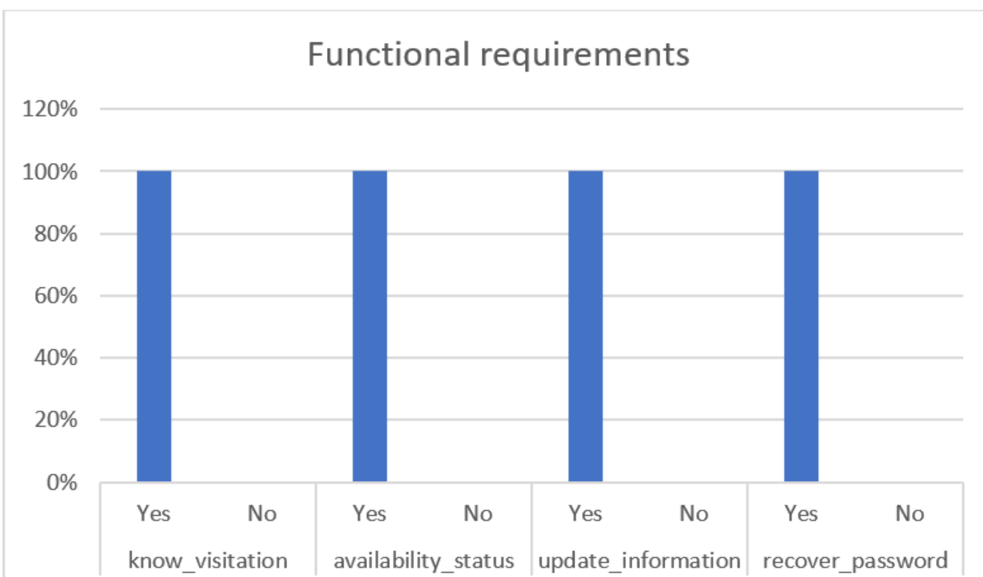

Figure 54: AINS web portal functional requirements

(vii) Validation for Non-Functional Requirement

Figure 55 shows the validation results for non-functional requirements for the AINS web portal. During validation, the user-friendly response scored 80% Yes and 20% no, effective scored 100%

yes, efficient scored 70% yes and 30%, useful scored 100% yes, stable scored 100% yes accurately scored 100% yes secured scored 80% yes and 20% no and reliable scored 80% yes and 20% no.

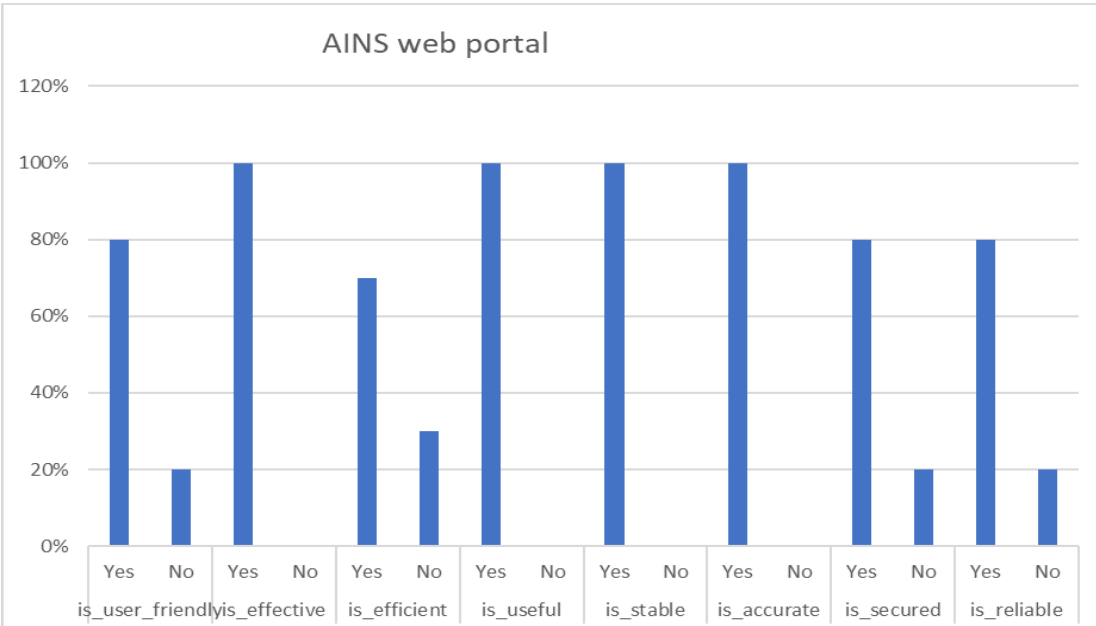

Figure 55: Non-functional requirement validation for AINS web portal

4.2 Discussion

This study aimed to enhance indoor navigation by developing an augmented reality application and web portal that are accessible to all users, including those with visual impairments. The results demonstrate a significant demand for technological innovations to improve the indoor navigation experience as similarly reported by Goldstein (2019) a report stating that indoor navigation is a growing field. The study found that while 50% of visually impaired individuals typically request guidance from others to reach their destinations, 20% rely on phone calls, and 15% use canes methods that are often inefficient due to factors such as the guide's unfamiliarity with the environment or the unavailability of help on the phone as reported by Khan and Khusro (2021) that most visually impaired rely on third-party assistance or white canes to assist them in navigation. The newly developed application, equipped with accessibility features, aims to address these issues by enabling visually impaired users to navigate independently this also aligns with (Hamid *et al.,* 2020) study that accessibility. According to the findings, 80% of these users affirmed the need for an application to assist in independent navigation. Key features they sought include the ability to identify their current location, audio-based directions for cues, and recognition of obstacles and landmarks for safety. Additionally, they expressed a desire for voice command functionality to interact with the application's features more effectively. These improvements could significantly enhance the safety and autonomy of visually impaired individuals while navigating indoors as stated by El-Sheimy and Li (2021a) that indoor navigation is essential in aiding users to navigate indoors, However, other studies have shown that accessibility features for users with visual impairments are often neglected in application development as reported in a study conducted by Kamaghe *et al.* (2020) stating that developers assume all users are the same during application development. This indicates that such features are typically considered afterthoughts rather than integral components to be incorporated during the development process. Understanding these features from the users' perspective is crucial for achieving true inclusivity.

Additionally, from the 60 participants including visitors, staff, and students, among those with visual impairments, the gender distribution was 45% males and 55% females. For students, the breakdown was 55% male and 45% female. The student group itself consisted of 50% new students, 35% continuing students, and 15% visitors. Results from focus group discussions with the students indicate that 50% of new students are likely to encounter challenges in accessing various services within campus buildings. This observation is supported by their suggestion for an indoor navigation system to help them locate classrooms, labs, and staff offices, preventing them from getting lost. This is similar to study done by Rubio-Sandoval *et al.* (2021) that the provision of information during navigation is important, however, in this study students expressed a desire to understand the availability status of staff members in the offices they wish to visit. This feature is crucial for saving time and allows students to act based on the staff's availability, leaving a message if the matter requires special attention. The functionality for searching destinations within the campus was also suggested as a feature to facilitate the search for an office by name or the name of the occupant, enhancing the ease of access and interaction with the application.

Furthermore, the study reveals that to track who visited the office, 55% of staff rely on phone calls, 15% receive notifications from the receptionist, and 30% are unaware of their visitors. Using phone calls is not an efficient method, particularly when visitors do not know the staff member's phone number. Dependence on receptionist notifications is also problematic, as it hinges on the receptionist's presence during visits. The lack of awareness about visitors leads to missed opportunities to understand the purpose of their visits and no effective way to follow up on matters related to their visits. The majority of staff interviewed expressed the need for a system that enables them to communicate with visitors directly. This system would allow staff to update their availability and other information, which visitors could access through an indoor navigation application. Additionally, staff suggested a feature in the staff availability update web portal that would allow them to see who visited their office and understand the visitors' intentions through messaging functionality in the system.

Moreover, the testing results indicated a pass for all tested functionalities of the application, including QR code scanning/WiFi fingerprinting, destination search, reading availability status, leaving messages for staff, and providing clear navigation. Audio cues and voice command functionalities were also tested for the application for people with visual impairment to be able to interact with the application. The tested functionalities of the web portal included login, registration, information updates, status updates, message reading, account recovery, and compliance with W3C accessibility standards. This compliance confirms that the web portal is accessible to all users.

The study utilized an RSSI dataset containing 10 000 data points to train machine learning models for predicting the initial location coordinates (X, Y) of a user. This dataset was sufficient to train both Random Forest and K-Nearest Neighbors (KNN) regressor algorithms, chosen for their suitability with continuous data. The performance of these algorithms was evaluated to determine the most effective model for location prediction. The Random Forest (RF) model out performed and a Mean Absolute Error (MAE) of 0.169. In comparison, the KNN model recorded an RMSE of 0.83, an MSE of 0.69, and an MAE of 0.21, indicating that RF was the superior choice for this problem. This localization technique is particularly reliable for visually impaired users, as the application can accurately identify the initial location or position of the user's device upon opening the application. Additionally, the integration of QR codes as an alternative positioning technique during WiFi unavailability enhances the functionality of the localization feature under various circumstances in comparison to the study done by (Ullah Khan *et al.,* 2019) who used reference images to determine users' starting point however, the multi localization method applied in this study add more for users with visual impairment to automatically localized once opening the application. The approach of using QR codes for localization faced challenges related to the orientation and pose of the QR code during scanning. If the QR code was not positioned in a stationary manner, it could lead to incorrect localization results. This issue was effectively resolved by permanently affixing the printed QR codes to the walls.

The prototype developed in this study was tailored to meet user requirements, ensuring alignment with collected specifications. Validation conducted at NM-MAIST and DHBW Heidenheim demonstrated the prototype's potential to address indoor navigation challenges within higher education environments, with all participants affirming the utility of its functionalities. These included locating facilities, providing directions, viewing staff availability, and saving time during navigation, underscoring the tool's practical relevance.

User testing results from DHBW showed that 83% of participants had prior experience with AR applications, while 18.7% had never used them, indicating a significant opportunity to expand the utilization of this technology to enhance awareness and foster innovation in the field. This shows that even in developed countries still AR applications have not been utilized to a large extent. Regarding usability, 52.5% of users found the application easy to use, and 22.2% found it very easy, highlighting its user-friendly design that facilitates straightforward interactions to achieve desired outcomes, confirming usability as stated by Fukuzumi *et al.* (2022) that usability shows the degree to which the developed application can be used by its users to achieve specific goals with satisfaction in the context of use. Challenges such as identifying the starting point and calibrating it with the QR code for localization were initially reported. These issues, primarily due to the instability of QR codes during scanning, were subsequently rectified. Features like the mini-map, easy room finding, and usage for safety reasons in case of fire were particularly appreciated, confirming the application's usability and effectiveness.

This study enhances educational technologies by improving indoor navigation in higher education institutions, particularly optimizing for users with visual impairments. It incorporates features such as audio cues and voice commands to facilitate user interaction with the application. Further research is needed to explore additional functionalities like object detection and identification, as well as haptic feedback, to enhance accessibility for users who are completely visually impaired.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study aimed to address the indoor navigation challenges in higher learning institutions by developing an accessible AR indoor navigation application that is optimized for visually impaired users. A case study of NM-AIST located in Arusha, Tanzania, and the DHBW in Heidenheim, Germany was used to accomplish the objectives of the study. A qualitative approach by employing an interview method was used to obtain the portal's development requirements and an indoor navigation application, and scrum agile development methodology was used in the entire phase of the development. The study has shed light on the current status of indoor navigation systems in higher learning institutions in Tanzania and globally and why implementing an accessible indoor navigation system is essential in learning institutions. The findings of the study have shown that users face challenges while navigating inside unfamiliar buildings, and sometimes, they waste time when visiting an office and cannot find its occupants. These challenges are even more common for people with visual impairment. The developed application accommodated accessibility features to help them navigate independently and reliably. While other navigation means have been used, including posters on the walls showing directions and using reception offices for inquiries, this study has found that an accessible augmented reality indoor navigation system with a web portal that allows staff to update their availability status can complement these other means. Furthermore, the indoor navigation application assists in obtaining directions for different locations within the building, including classrooms, offices, washrooms, and emergency applications, as well as knowing the availability status of office occupants. The findings of this study imply that applications of immersive technologies such as augmented reality can be efficient by providing a real-time experience while enhancing the user's real-world view. Also, the developed prototype aims to tackle the existing demand for indoor navigation systems for different use cases. The prototype can be customized easily to be adopted in other settings.

5.2 Recommendations

The study recommends the need for research into policies and standards governing augmented reality systems. Understanding the best practices for systems developed with this technology is essential for ensuring quality and reliability. Additionally, the study recommends conducting a comprehensive study focused on evaluating system security vulnerabilities. This includes identifying and mitigating risks such as SQL injection, cross-site scripting, broken authentication, and brute force attacks. Such a study would play a vital role in fortifying the security framework of augmented reality systems, thereby ensuring their safe and effective use in various environments.

Furthermore, the study recommends the development of more customizable AR indoor navigation systems to foster sustainability and facilitate the adoption of these solutions in various settings and use cases. In addition, more effective localization algorithms and methods should be explored, such as leveraging machine learning and artificial intelligence. These technologies could enhance system functionalities, offering advanced features like scene understanding, object detection and recognition. Such enhancements would not only improve user experience but also extend the system's applicability for diverse user groups.

5.2.1 Future Work

The future work of this project includes the implementation phase at DHBW where the application for indoor navigation will be deployed. The implementation will include several steps, including additional of other features such as machine learning for object detection and recognition. Future enhancements will also involve adding functionalities to the web portal, such as the ability to upload maps and determine paths, rather than only relying on the application for these tasks. Moreover, the application will be adapted to accommodate users with hearing impairments. The project will also prioritize usability tests for users who are completely blind, aiming to identify and address their specific challenges to ensure a functional product. Furthermore, the study will explore the use of visual positioning system (VPS) technology to enhance the indoor navigation experience.

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APPENDICES

Appendix 1: Focus group discussion guide with students

Gender

i. Male
ii. Female

Type of student

i. New
ii. Continuing
iii. Visiting student

Level of study

i. Masters
ii. PhD

Year of Study

i. One
ii. Two
iii. Three
iv. Four
v. More than four

School

i. COCSE
ii. LISBE
iii. MEWES
iv. BUSH

Age Level

1. 20 - 25
2. 26 - 30
3. 31 – 35
4. 36 – 40
5. 41+

What do you do when you are looking for a class or an office that you don’t know its location?

i. Ask the receptionist or someone around
ii. Searching until finding
iii. Call the office occupants
iv. Check a guide map
v. Read sign boards

Do you think the current way of looking for facilities that you don’t know such as a class or an office that you don’t know is efficient enough?

i. Yes
ii. No

Do you think you will use the application to assist you in finding the facilities that you are looking for?

i. Yes
ii. No
iii. Neutral

As a student what features would you like an application that will assist you in finding the facilities you are looking for to have?

Answer format

As…………………………… I want ……………………………. So I can……………………

Appendix 2: Interview Guide for Staff

Opening Questions

1. Would you mind if we conduct this interview in your office or do you have an idea of another place that is more comfortable?
2. Can I know a little about yourself and what is the name of your department?
3. How long have you been working in this company?
4. Do you have any questions for me before we continue with our interview?

Key Questions

1. How do provide directions for a visitor to reach your office?
2. How do you know if someone visited your office when you were not around?
3. How do you provide a status to your visitors about your availability in the office?

Concluding Questions

1. Do you think having a system to automate the processes asked on questions 1 to 3 will be an effective means?

a. Yes

b. No

2. What features would you like the system in question 4 to have? And
3. What would be the benefits of having the system?

Appendix 3: Interview Guide for Visually Impaired

Opening Questions

5. Would you mind if we conduct this interview in your office or do you have an idea of another place that is more comfortable?
6. Can I know a little about yourself and what is the name of your department?
7. Do you have any questions for me before we continue with our interview?

Key Questions

4. What is the current way of looking for facilities that you don't know such as a class or an office that you don't know is efficient enough?
5. Has any issue or problem occurred when using the current way?
6. What is important for you to know when you are been given directions to reach a facility that you don't know such as a class or an office?

Concluding Questions

4. Do you think you will use the application to assist you in finding the facilities that you are looking for?
a. Yes
b. No
5. As a visually impaired person what features would you like an application that will assist you in finding the facilities you are looking for to have?

Appendix 4: Source codes samples

i. Snap shot of codes for fetching users' status

```
using TMPro;

public class StatusDataRetrived : MonoBehaviour
{
    [SerializeField] private TMP_Text _statusText;
    [SerializeField] private TMP_Text _fullNameText;
    [SerializeField] private TMP_Text _office_no;
    [SerializeField] private TMP_Text _email;

    public static string office_name = string.Empty;
    public static string email_address = string.Empty;
    public static string _status = string.Empty;
    public static string _fullname = string.Empty;

    // Static list to store email addresses
    public static List<string> emailAddresses = new List<string>();

    public void SetEmployeeData(Employee employee)
    {
        if (employee == null) return;
        if (_fullNameText != null) _fullNameText.text = employee.fullname;
        if (_statusText != null) _statusText.text = employee.status;
        if (_office_no != null) _office_no.text = employee.office_no;
        if (_email != null) _email.text = employee.email;

        office_name = _office_no != null ? _office_no.text : string.Empty;
        email_address = _email.text != null ? _email.text : string.Empty;
        _status = _statusText.text != null ? _statusText.text : string.Empty;
        _fullname = _fullNameText.text != null ? _fullNameText.text : string.Empty;

        // Add the email address to the list
        if (!string.IsNullOrEmpty(email_address))
        {
            emailAddresses.Add(email_address);
        }

        LogOfficeName();
        Status();
        FullName();
    }
```

iii. Snapshot showing part of random forest machine learning model

```
TGAN.ipynb
TGAN.ipynb > import pandas as pd

import joblib
joblib.dump(rf, 'random_forest_model2.pkl')

import pandas as pd
rf_model = joblib.load('random_forest_model2.pkl')

#Here I have tested data from 10th Row you can test any row from your Original Data... you can see the prediction output is ac
input_data = pd.DataFrame([[-64,-86,-90,-89]], columns=['NMAIST_D','NMAIST_B','NMAIST_C','CDAC_14'])

predicted_output = rf_model.predict(input_data)

print("Predicted 'OUTPUT (X)':", predicted_output[0][0])
print("Predicted 'OUTPUT (Y)':", predicted_output[0][1])

[5]                                                        Python

Predicted 'OUTPUT (X)': 3.5799113289483255
Predicted 'OUTPUT (Y)': 11.513598929684242
```

RESEARCH OUTPUTS

(i) Publication

Samson, F., Dida, M. A., Leo, J., Shidende, D., Naman, G., & Moebs, S. (2023). *Accessibility Features for Augmented Reality Indoor Navigation Systems. In International Conference on Emerging Technologies for Developing Countries (pp. 37-53). Cham: Springer Nature Switzerland.*

(ii) Best paper award

(iii) Poster presentation

Best paper award

BEST PAPER
AWARD

6th EAI International Conference on

Emerging Technologies for Developing Countries

December 12-13, 2023 | **Arusha, Tanzania**

Presented to:

Frank Samson

For the paper entitled:

Accessibility Features for Augmented Reality

Indoor Navigation Systems

EAI INNOVATING RESEARCH

AFRICA TEK

Poster presentation

DEVELOPMENT OF AN ACCESSIBLE AUGMENTED REALITY APPLICATION TO ENHANCE INDOOR NAVIGATION. A CASE OF HIGHER LEARNING INSTITUTIONS

Student: Frank Samson
Supervisors: Dr. Mussa Dida, Dr. Judith Leo, Prof. Sabine Mobs

Affiliations:
Nelson Mandela African Institution of Science and Technology(NM-AIST),
Duale Hochschule Baden-Württemberg Heidenheim (DHBW)

PROJECT DESCRIPTION

This project aimed to develop an accessible augmented reality (AR) indoor navigation tool which will be built using an open source framework with a case study in two learning institutions: NM-AIST and DHBW Heidenheim. Its main objective is to address the challenges of indoor navigation faced by new students, staff, and visitors while navigating inside unfamiliar buildings regardless of their impairments. To enhance location tracking during navigation, simultaneous localization and mapping (SLAM) technology will be utilized. Additionally, the tool will incorporate a web-based portal, enabling staff members to update their availability status from their offices, which will be reflected in the developed tool. By creating this AR navigation tool, we aim to provide an inclusive and user-friendly solution for effective indoor navigation within educational campuses

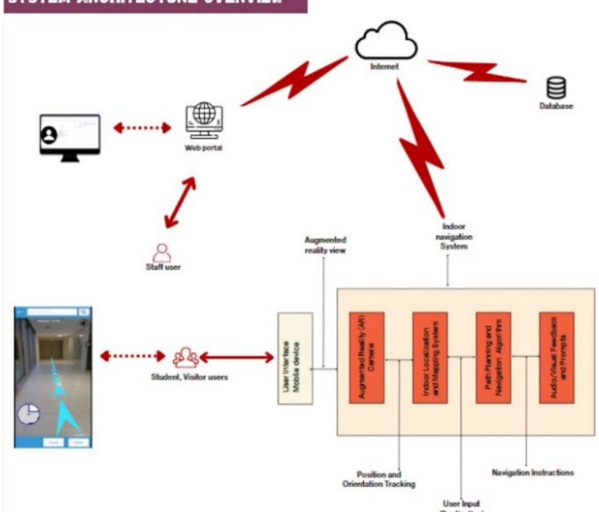
SPECIFIC OBJECTIVES

- To identify the requirements for developing an accessible augmented reality tool for indoor navigation in the learning environment.
- To develop an accessible augmented reality tool for indoor navigation in the learning environment.
- To validate the the developed system

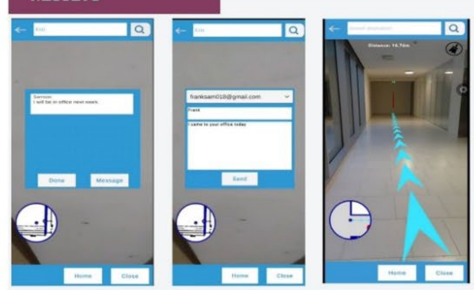
MATERIAL AND METHODS

- The project employed a qualitative research approach to gather requirements, utilizing both primary and secondary sources of data. Interview, document review and focus group discussion will be employed.
- The project's target population was students, staffs and visitors with is different abilities particularly with vision impairment who faces challenges when walking inside buildings of the learning institutions.

SYSTEM ARCHITECTURE OVERVIEW



RESULTS



CONCLUSION

- Indoor navigation system will improve people's navigation experience
- Accessibility features of the system will provide independent navigation for people with impairment
- The open source nature of the tool will provide an easy way for other institution to adopt and use the tool in their context.

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