Artificial Intelligence-based Smarter Accessibility Evaluations for Comprehensive and Personalized Assessment

Sayeda Farzana Aktar
Marquette University

Artificial Intelligence-based Smarter Accessibility Evaluations for Comprehensive and Personalized Assessment

by

Sayeda Farzana Aktar

A Dissertation submitted to the Faculty of the Graduate School,
Marquette University,
in Partial Fulfillment of the Requirements for
the Degree of Doctor of Philosophy

Milwaukee, Wisconsin

August 2023

ARTIFICIAL INTELLIGENCE-BASED SMARTER ACCESSIBILITY EVALUATIONS FOR COMPREHENSIVE AND PERSONALIZED ASSESSMENT

Sayeda Farzana Aktar

Department of Computer Science
Marquette University, 2023

The research focuses on utilizing artificial intelligence (AI) and machine learning (ML) algorithms to enhance accessibility for people with disabilities (PwD) in three areas: public buildings, homes, and medical devices. The overarching goal is to improve the accuracy, reliability, and effectiveness of accessibility evaluation systems by leveraging smarter technologies. For public buildings, the challenge lies in developing an accurate and reliable accessibility evaluation system. AI can play a crucial role by analyzing data, identifying potential barriers, and assessing the accessibility of various features within buildings. By training ML algorithms on relevant data, the system can learn to make accurate predictions about the accessibility of different spaces and help policymakers and architects design more inclusive environments. For private places such as homes, it is essential to have a person-focused accessibility evaluation system. By utilizing machine learning-based intelligent systems, it becomes possible to assess the accessibility of individual homes based on specific needs and requirements. This personalized approach can help identify barriers and recommend modifications or assistive technologies that can enhance accessibility and independence for PwD within their own living spaces. The research also addresses the intelligent evaluation of healthcare devices in the home. Many PwD rely on medical devices for their daily living, and ensuring the accessibility and usability of these devices is crucial. AI can be employed to evaluate the accessibility features of medical devices, provide recommendations for improvement, and even measure their effectiveness in supporting the needs of PwD. Overall, this research aims to enhance the accuracy and reliability of accessibility evaluation systems by leveraging AI and ML technologies. By doing so, it seeks to improve the quality of life for individuals with disabilities by enabling increased independence, fostering social inclusion, and promoting better accessibility in public buildings, private homes, and medical devices.

ACKNOWLEDGEMENTS

Sayeda Farzana Aktar, M.S.

I want to express my deep gratitude to my adviser, Dr. Sheikh Iqbal Ahamed, for his continuous support and feedback throughout my Ph.D. career. He always encouraged me throughout my research journey and directed me with his valuable advice and expertise.

I would like to extend my heartfelt appreciation to Dr. Roger O. Smith and Dr. Tahimidul Islam for their invaluable contributions as members of my dissertation committee. Their dedication of time, insightful comments, and feedback have been truly invaluable. I am especially grateful to Dr. Roger 0. Smith for his exceptional guidance and support throughout every stage of the research. Furthermore, I would like to express my gratitude to Dr. Stephan Andrei and Dr. Altaf Sarker for being a source of inspiration and for their unwavering support, which played a significant role in my decision to pursue a PhD.

I would like to extend my appreciation to my present and past colleagues at the R2D2 lab and Ubicomp Lab for their continuous cooperation throughout the years. Their support has been invaluable to me. Additionally, I am grateful to the amazing community in Milwaukee for their unwavering assistance and constant presence. Thanks to these exceptional individuals, I have never felt the absence of being away from my family in the past few years.

The most significantly, I want to express my deepest gratitude to my parents, the late Syed Kh. Altaf Hossain and Kohinur Aktar, who always had grand aspirations for me. Words cannot adequately convey how fortunate I am to be their daughter. Their boundless love and sacrifices throughout my entire life are beyond measure, and I can never thank them enough. I am also grateful to my sisters, Syeda Asma Aktar, Syeda Hasna Aktar, and Syeda Irin Aktar, as well as my brother, Syed Tanjid Rubayth, for their unwavering support and constant inspiration. Having them in my life is a tremendous blessing that I cherish deeply.

Lastly, I would like to acknowledge the funding organization for, MED-AUDIT project of the Rehabilitation Engineering Research Center on Accessible Medical Instrumentation project and this work was supported in part by the National Institute on Disability and Rehabilitation Research (NIDRR), grant number H133E020729. The opinions contained in this dissertation do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government. Aslo the work of the Access Rating for Buildings project was supported by grants from the National Institute on Disability, Independent Living, and Rehabilitation Research, NIDILRR grant number 90IFDV0006 and NIDIRR grant number H133G100211. NIDILRR is a Center within the Administration for Community Living (ACL), Department of Health and Human Services (HHS). The contents of this work do not necessarily represent the policy of NIDILRR, ACL, HHS, and you should not assume endorsement by the Federal Government. The HESTIA Project is supported in part by the U.S. Department of HHS/ACL, National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR), grant number 90IF0083-01-00. The opinions contained in this dissertation do not necessarily represent the policy of the Department of HHS, and you should not assume endorsement by the Federal Government. The HESTIA Project is supported in part by the U.S. Department of HHS/ACL, National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR), grant number 90IF0083-01-00. The opinions contained in this dissertation do not necessarily represent the policy of the Department of HHS, and you should not assume endorsement by the Federal Government. And this work was developed in part under a grant from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR grant number 90DPGE0016). NIDILRR is a Center within the Administration for Community Living (ACL), Department of Health and Human Services (HHS). The content of this work does not necessarily represent the policy of NIDILRR, ACL, HHS, and you should not assume endorsement by the Federal Government.Moreover, the contents of this thesis were developed under a grant from the Department of Education, National Institute on Disability and Rehabilitation Research (NIDRR), grant number H133E100007. However, those contents do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government.The ATOMS Project and this work was supported in part by the National Institute on Disability and Rehabilitation Research (NIDRR), grant number H133A010403. The opinions contained in this dissertation do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1
Introduction

1.1 Problem Statement

Accessing community buildings can be challenging for individuals with disabilities [1]. In the United States alone, an estimated 61 million people have some form of disability [8]. Among them are 8.4 million individuals with mobility impairments, 6.5 million with cognition disabilities, and 4.1 million with independent living disabilities. Additionally, 3.5 million individuals are deaf or have significant hearing difficulties, 2.8 million have visual impairments, and 2.2 million have self-care disabilities. This accounts for approximately 25 percent of U.S. adults experiencing some form of disability [9], [10].

The accessibility of public buildings and homes is crucial for PwD within the community [11], [12]. The Americans with Disabilities Act (ADA), established in 1990 and updated in 2010 (ADA-ABA), has made previously inaccessible public structures accessible for thousands of PwD [13]. However, despite these efforts at societal and community levels, inaccessible environments still hinder the full participation of PwD in society. Assessing and analyzing accessibility barriers in buildings remains challenging and time-consuming, as finding relevant, reliable, and comprehensive assessments is difficult [12]. Moreover, existing accessibility measurement tools primarily focus on the physical aspect of accessibility in objective analysis, neglecting the subjective analysis that considers the needs of individuals with cognitive, visual, or hearing impairments [14]. This lack of comprehensive information can lead to PwD staying home rather than facing potential hardships, resulting in reduced community participation and independence. Therefore, accurately identifying accessibility barriers beforehand is crucial for independence and active engagement [11]. This is where technology can play a significant role, enabling rehabilitation professionals to enhance current practices and promote the participation and independence of PwD [9], [1].

Additionally, the lack of accessibility information and the inaccessibility of medical devices contribute to healthcare disparities and impede timely treatment for people with disabilities (PwD) when making informed decisions about home medical devices. While there are regulations and guidelines regarding accessibility, there is a dearth of strategies to provide accessibility information specifically tailored to PwD [15]. Findings from a national survey indicate that a significant proportion of PwD encounter challenges in using their devices and express dissatisfaction with their purchases. However, they emphasize the need for greater accessibility of information to facilitate their decision-making process when selecting medical devices. Previous research further underscores the difficulties and disparities faced by PwD due to the inaccessibility of medical devices [1], [14].

This article addresses the primary challenges associated with measuring accessibility, particularly in buildings, homes, and home medical devices. Also, proposed potential solutions to overcome these challenges. It highlights the importance of accurate accessibility measurements and their impact on community buildings, homes, and home medical devices. Additionally, it presents three proposed solutions to establish valid, reliable, and time-efficient assessments: Access Rating for Buildings (ARB) for building accessibility measurement, myHESTIA for individual home accessibility evaluation, and MED-Audit for measuring accessibility of home medical devices. These systems aim to provide comprehensive and personalized accessibility information (PAI) about public buildings, homes, and medical devices to PwD. The project intends to optimize the system using Artificial Intelligence (AI) techniques and evaluate its impact on PwD's decision-making process. The successful implementation of this project could contribute to improved accessibility measurement and evaluation of building design and medical device design and serve as a strategy for providing PAI in various product and environmental contexts.

1.2 Research Aims

The objective of this research is to develop system solutions for measuring the accessibility of public buildings, homes, and home medical devices. The study also explores how artificial intelligence (AI) can enhance existing systems to provide more reliable, efficient, valid, comprehensive, and personalized measurements of public building accessibility. Additionally, the research aims to propose smart and automated reports for home accessibility, as well as assist in the design and selection of the most suitable and accessible medical devices.

The system solution that has been developed incorporates user feedback, expert feedback, and feedback from PwD to accessibility measurement. The conventional approach of using subjective questionnaires to measure accessibility is challenging due to potential participant bias and device hardware limitations. This research addresses this significant issue by employing machine learning (ML) techniques and computational analysis to optimize the accessibility measurement process. Additionally, the research introduces various AI-based solutions based on hypothetical data and theoretical analysis, demonstrating how AI models can help overcome the existing challenges in accessibility measurement. The research aims are

1) To Measure the Accessibility of Health care Devices Intelligently.

2) To Enhance the Validation of Accessibility Evaluations of Public Buildings Intelligently.

3) To Evaluate Home Accessibility using a Machine Learning based Intelligent System.

1.3 Publications

- **Sayeda Farzana Aktar**, Mason Dennis Drake, Shiyu Tian, Dr. Roger O Smith, Dr. Sheikh Iqbal Ahamed, (2023) A Machine Learning-Based Approach to Enhance the Accuracy of Sound Measurements in iOS Devices for Accessibility Applications, Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) Annual Conference, New Orleans, Louisiana

- **Sayeda Farzana Aktar**, Shiyu Tian, Kazi Shafiul Alam, Mason Dennis Drake, Laryn Michele O'Donnell, Roger O Smith and Sheikh Iqbal Ahamed (2023) Mobile Appication Based Solution for Building Accessibility Assessment for Comprehensive and Personalized Assessment, COMPSAC 2023 (IEEE Computer Society Signature Conference on Computers, Software, and Applications) Annual Conference, Torino, Italy.

- Rochelle J. Mendonca, Maysam M. Ardehali, **Sayeda Farzana Aktar**,Dr. Roger O Smith, (2023) Interrater Reliability of the MED-AUDIT (Medical Equipment Device – Accessibility and Universal Design Information Tool), Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) Annual Conference, New Orleans, Louisiana.

- Mason Dennis Drake, Steven C. Sizer, **Sayeda Farzana Aktar**,Dr. Roger O Smith, Dr. Sheikh Iqbal Ahamed (2023) myAccessTools: Validation of Impairment-Weighted Scores, Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) Annual Conference, New Orleans, Louisiana.

Chapter 2
Literature Review

A few studies focus on the challenges and issues pertaining to accessibility measurement of public buildings, homes, and home medical devices. This section will examine various studies that have delved into these concerns. Furthermore, the systematic review presented here sheds light on the contributions made by other researchers and their findings concerning different aspects of accessibility measurement. It also outlines the role of AI in enhancing accessibility measurement more intelligently. The researchers identified nine significant problem groups related to accessibility measurement, discussed in Chapter 4. These mappings served as the foundation for developing multiple solutions and AI-based recommendations to improve accessibility measurement.

A study carried out in 2020 examined the growing importance of transit accessibility in fields like transport planning, urban geography, and sustainable development. The researchers emphasized the critical role of accurate measurements of transit accessibility in the design of transit networks, evaluation of transit systems, and land use and transport planning in urban areas. The review provided insights into both the practical advantages and limitations of these accessibility measurement models, offering a comprehensive perspective on the topic [16].

In a research study conducted by Kane et al. [7], the focus was on investigating the differences in gestures employed by blind and sighted individuals when using touch screen devices. The primary objective of the study was to establish guidelines for designing accessible touch-screen interfaces. The research involved 10 blind participants and 10 sighted participants who were instructed to create gestures to execute various computing commands. By comparing the gestures used by both groups, the study aimed to gain insights into the unique gesture preferences and requirements of blind individuals for touch screen interactions [17].

In recent years, there has been a focus on proposing mobile accessibility guidelines to ensure the development of software solutions that are accessible to visually disabled users. In a study conducted by Piccolo et al. [8], a set of guidelines was defined to create an accessible software solution for individuals with visual disabilities. The research examined how people with visual impairments interact with mobile devices, providing valuable insights for designing accessible mobile applications. Additionally, Park et al. conducted a study that proposed ten heuristics to guide the development of accessible mobile applications. The authors emphasized the importance of providing practical heuristics to support developers and designers in creating mobile applications that are accessible to all users, including those with visual disabilities. These studies contribute to advancing mobile accessibility by offering specific guidelines and heuristics to improve the accessibility of mobile software solutions, thus ensuring a more inclusive user experience for individuals with visual impairments [18].

In a research study conducted by Ghidini et al. [19], the focus was on investigating interaction strategies that would enhance the experience of visually-disabled users when using mobile devices. The study employed a survey approach involving six participants, gathering information on their usage of a native calendar app on the Android operating system. Participants were also asked to provide suggestions for improvements. Additionally, the researchers developed a prototype of an accessible calendar app and conducted usability tests with users [19], [3]. The study's findings indicated that mobile devices, particularly smartphones, should offer appropriate feedback to visually-disabled users. The interface design should aim to keep interactions as simple as possible, and there should be options to adjust the interface's color. Additionally, it was essential to ensure that users could quickly identify the features and options available within the application. This research highlights the significance of providing accessible features and user-friendly designs for visually-disabled individuals using mobile devices, particularly calendar applications. The results provide valuable insights for improving the accessibility and usability of such applications to serve the needs of visually-disabled users better [19].

Kim et al. [20], [21], conducted a study to examine how visually-disabled users interact with camera-based applications on smartphones and its implications for designing assistive technologies. The research involved recruiting twenty participants and conducting usability tests to gather insights. The results yielded significant implications for design, including the importance of providing consistent and simply-structured user interface (UI) layouts. Additionally, the study highlighted the need to increase configurable settings to enhance the accessibility of mobile applications for visually-disabled users. This research sheds light on the interaction patterns and preferences of visually-disabled individuals when using camera-based applications on smartphones. The findings offer valuable guidance for the design and development of assistive technologies that improve the accessibility and usability of these applications for visually-impaired users [22], [23].

Damaceno et al. [24] conducted a study to identify and map accessibility issues encountered by people with visual disabilities on mobile devices. The research question addressed was "What are the accessibility problems that people with visual disabilities encounter on mobile devices?". The study mapped the encountered problems into several categories, including lack of physical buttons, challenges related to data entry, gesture-based interaction, screen reader functionality, screen size limitations, user feedback issues, and difficulties with voice commands. Each category presented unique problems, and the authors provided corresponding recommendations for the identified issues. Overall, the study contributes valuable insights into the accessibility problems experienced by people with visual disabilities on mobile devices [25]. It presents categorized issues and provides recommendations as a foundation for future research. However, further investigation is needed to explore the differences between the accessibility of native apps and websites and better understand the impact of these issues on disabled users [25].

To address the lack of comprehensive accessibility guidelines for mobile devices, a study conducted by Siebra et al. [26] analyzed 247 scientific papers to establish requirements catering to individuals with diverse needs. The dataset identified 36 mandatory and 18 desirable requirements, which were categorized into different groups and subgroups based on impairments like hearing, vision, and motor. The study emphasized 13 specific accessibility requirements relevant to visually-disabled individuals, such as clear feedback, color-independent design, and proper labeling [26]. To delve further into the accessibility issues experienced by visually-disabled and mainstream users on websites and native applications, the researchers engaged 10 participants in the study, including six blind users and four mainstream users. Usability tests were conducted on a selection of 4 websites and their corresponding native applications from commercial and governmental organizations. The evaluation revealed 514 problems, with blind users encountering 409 problems and normal-vision users encountering 105 problems. The study highlighted the most frequent and severe issues faced by blind users in mobile applications and websites, comparing their impact to that experienced by mainstream users. The findings presented initial evidence of critical problems requiring attention in developing mobile applications and websites. This underscores the importance of conducting further comprehensive investigations into the accessibility challenges faced by individuals with visual disabilities. Additionally, the research underscored that blind users are significantly more affected by these issues on mobile devices than users with normal vision [26].

With the increasing prevalence of mobile technology, a study by Revilla [27] in October 2016 revealed that mobile devices surpassed desktops and laptops regarding web page loads for the first time. This shift emphasizes the need for research studies on web and application accessibility for desktop platforms and mobile websites and applications. Web accessibility guidelines, such as the internationally-recognized Web Content

Accessibility Guidelines (WCAG) [28] developed by the Web Accessibility Initiative (WAI) of the World Wide Web Consortium (W3C), have been established to assist developers and designers in creating accessible web content. However, while web accessibility has been extensively studied, mobile accessibility research initiatives are still comparatively limited. The W3C [17] recently published the first public working draft on applying WCAG 2.0 and other W3C/WAI guidelines to mobile devices in response to this gap. Additionally, the BBC [29] has published standards and guidelines for mobile web content, hybrid, and native apps based on their experiences, aiming to support developers in achieving mobile accessibility. While both web and mobile accessibility guidelines contribute to improving content accessibility for diverse needs, a study by Power et al. [30] indicated that only 50.4 percent of the problems encountered by blind users on desktop websites were covered by WCAG 2.0, and a mere 8.4 percent of all problems were addressed by websites implementing these guidelines. These findings suggest a lack of empirical evidence regarding the nature of accessibility issues faced by visually disabled users. In the context of mobile devices, there is an even more remarkable dearth of evidence to understand the nature of problems encountered by users and how to address them. This paper aims to collect and examine empirical evidence of problems encountered by visually disabled users on mobile platforms, characterize the frequency and severity of critical issues, and compare the impact of these problems on visually disabled users versus users with normal vision.

Moreover, many existing research publications highlight various accessibility challenges in public buildings. These challenges include the absence of ramps or elevators and insufficient accessible parking spaces near the entrance pose challenges for individuals with mobility disabilities who rely on convenient access. Narrow doorways, hallways, and corridors hinder the easy movement of wheelchair users and individuals with mobility aids. Moreover, insufficient visual cues and signage within the building can be problematic for individuals with visual impairments. The inaccessible restrooms with narrow doorways, lack of grab bars, or limited space for wheelchair maneuvering create challenges for people with mobility impairments who require independent use of facilities. Furthermore, service counters and reception desks that are too high create barriers for wheelchair users or individuals with reaching difficulties. Additionally, inadequate lighting and poor acoustics impact individuals with visual or hearing from engaging in important tasks rquiring primary sense. Ideally, public buildings would incorporate assistive technologies, such as hearing loop systems or closed captioning services, to accommodate individuals with hearing impairments, but often don't. Moreover, inaccessible emergency evacuation plans and exits compromise the safety of individuals with disabilities during emergencies. Clear evacuation routes and accessible emergency exits are crucial to ensure the well-being of all occupants . These challenges underscore the importance of incorporating universal design principles and complying with accessibility standards and guidelines to create inclusive public spaces. In addition, most of the existing research focused on accessibility measurement tools mostly focus on the physical component of accessibility in the objective analysis rather than considering the needs of people with cognitive, visual, or hearing impairments in the subjective analysis [7]. In contrast, this research paper focused on both subjective and objective analysis.

Chapter 3
To Measure the Accessibility of Health care Devices Intelligently

Home medical devices are medical devices that are designed for use in a home setting by individuals who require medical care or monitoring outside of a healthcare facility. These devices are typically intended for self-use or use by a caregiver under the guidance of a healthcare professional. Home medical devices can serve various purposes and cater to different healthcare needs. Some common examples include:

i) Blood Glucose Monitors- These devices are used by individuals with diabetes to monitor their blood glucose levels regularly. They typically involve a small lancet to obtain a blood sample, which is then analyzed by the device to provide glucose readings [31].

ii) Blood Pressure Monitors- These devices allow individuals to measure and track their blood pressure levels at home. They often include an arm cuff or wrist strap that is inflated to measure blood pressure [31], [32].

iii) Pulse Oximeters- Pulse oximeters measure the oxygen saturation level in a person's blood. They are commonly used by individuals with respiratory conditions or during physical activity to monitor oxygen levels [31].

iv) Home Ventilators- Ventilators are used by individuals who require assistance with breathing due to respiratory conditions. Home ventilators are designed for use outside of a hospital setting to provide continuous or intermittent respiratory support [31].

v) Nebulizers- Nebulizers are devices that convert liquid medication into a fine mist for inhalation. They are commonly used to deliver medication directly to the lungs for individuals with respiratory conditions, such as asthma or chronic obstructive pulmonary disease (COPD) [31], [32].

vi) Continuous Glucose Monitoring (CGM) Systems- CGM systems are used by individuals with diabetes to continuously monitor their glucose levels throughout the day.

These systems typically consist of a small sensor inserted under the skin and a receiver or smartphone app to display glucose readings [31].

vii) Home Dialysis Machines- Home dialysis machines are used by individuals with kidney failure to perform dialysis treatment at home. These machines filter waste and excess fluids from the blood, replicating the function of a dialysis center [31].

These are just a few examples of the wide range of home medical devices available. Home medical devices provide individuals with greater independence and convenience in managing their healthcare needs while staying in the comfort of their own homes [32].

3.1 Why accessibility information home medical devices is important?

Enabling individuals with disabilities (PwD) to lead independent lives is a crucial obligation of contemporary society. One essential aspect of independence is the freedom to select and acquire consumer products, including medical supplies, for everyday use. Unfortunately, there is a significant lack of accessibility information regarding medical products, which hinders PwD from making well-informed decisions [31]. The inaccessibility of medical products not only impedes timely access to necessary treatments but also contributes to significant healthcare disparities among individuals with disabilities [31], [33], [34]. Accessibility information for home medical devices is important for several reasons-

Equal Access to Healthcare: Accessible information ensures that individuals with disabilities or accessibility needs can access and use home medical devices effectively. It promotes equal access to healthcare technologies, allowing individuals to manage their health conditions and receive necessary medical care independently [33].

Empowerment and Independence: Accessible information enables individuals to take control of their healthcare and make informed decisions about their treatment. It empowers them to monitor their health, follow medical instructions, and engage in self-care, promoting a sense of independence and autonomy [35].

Safety and Effective Use: Accessible information helps users understand how to properly operate and maintain home medical devices, reducing the risk of accidents, errors, or misuse. It ensures that individuals can use the devices safely and effectively, minimizing potential harm or complications [36], [37].

User-Centered Design: Providing accessibility information encourages device manufacturers to consider the diverse needs of users during the design and development process. It promotes user-centered design principles, leading to the creation of more inclusive and usable home medical devices that cater to a broader range of individuals [33], [38].

Compliance with Regulations and Standards: In many countries, accessibility standards and regulations exist to ensure that medical devices are accessible to all users. Accessible information helps device manufacturers comply with these requirements, promoting inclusivity and preventing discrimination against individuals with disabilities [33].

Caregiver Support: Accessible information also benefits caregivers who assist individuals in using home medical devices. Clear instructions and user-friendly interfaces enable caregivers to provide effective support, reducing the burden and improving the quality of care [39].

Overall, accessibility information for home medical devices is crucial for promoting equitable access to healthcare, enabling individuals to manage their health conditions independently, ensuring safe and effective device use, encouraging inclusive design practices, and complying with accessibility regulations and standards.

3.2 Why accessible home medical device is important?

Accessible home medical devices are important for several reasons:

Independent Living: Accessible home medical devices empower individuals with disabilities or accessibility needs to live independently and manage their healthcare at home. They provide the tools and resources necessary for individuals to monitor their health conditions, administer treatments, and carry out essential medical tasks without constant reliance on healthcare professionals.

Enhanced Quality of Life: Accessible home medical devices improve the quality of life for individuals with disabilities or chronic conditions. By having access to devices that are specifically designed to meet their needs, individuals can effectively manage their health, reduce complications, and maintain a better overall well-being [40].

Timely Intervention and Monitoring: Home medical devices allow for regular monitoring of health conditions and early intervention when necessary. Individuals can track vital signs, measure blood glucose levels, monitor oxygen saturation, or administer medication, which helps them identify any changes or abnormalities promptly. This timely intervention can prevent health complications and improve health outcomes [37].

Cost-Effectiveness: Home medical devices can contribute to cost savings for both individuals and healthcare systems. By enabling individuals to manage their healthcare at home, it reduces the need for frequent hospital visits, emergency room admissions, or long-term care facilities. This can result in lower healthcare costs and more efficient allocation of resources [35].

Convenience and Comfort: Accessible home medical devices provide convenience and comfort to individuals by allowing them to receive necessary medical care in the comfort of their own homes. This eliminates the need for frequent travel to healthcare facilities, long waiting times, and disruptions to daily routines. It promotes a sense of familiarity and control over one's healthcare [14].

Caregiver Support: Accessible home medical devices not only benefit individuals but also provide support to caregivers. These devices enable caregivers to assist individuals more effectively, monitor their health remotely, and provide timely interventions when needed. This support can reduce caregiver burden and enhance the overall caregiving experience [41].

Inclusive Healthcare: Accessible home medical devices promote inclusivity in healthcare by ensuring that individuals with disabilities or accessibility needs have equal access to necessary medical technologies. It eliminates barriers and discrimination, allowing individuals to actively participate in their healthcare and access the same level of care as others [42].

The accessible home medical devices play a crucial role in enabling independent living, improving quality of life, facilitating timely intervention, reducing healthcare costs, providing convenience and comfort, supporting caregivers, and promoting inclusive healthcare for individuals with disabilities or accessibility needs.

3.3 What are the accessibility challenges for home medical devices?

There are several accessibility challenges associated with home medical devices

3.3.1 Physical Accessibility

Physical accessibility refers to the design and usability of the device for individuals with mobility impairments. Some challenges include devices with small buttons or touchscreens that are difficult to operate for individuals with limited dexterity or fine motor control. Additionally, the placement of devices, such as height or reachability, may pose challenges for individuals with mobility limitations [43].

3.3.2 Visual Accessibility

Visual accessibility relates to the design and display of information on the device for individuals with visual impairments. Challenges can include devices with small or poorly contrasted displays, lack of alternative text or audio output for visual information, or complex interfaces that are difficult to navigate without visual cues [42], [44].

3.3.3 Auditory Accessibility

Auditory accessibility pertains to the provision of audio information or alerts for individuals with hearing impairments. Challenges may arise when devices heavily rely on auditory cues, alarms, or instructions without alternative visual or tactile feedback [24].

3.3.4 Cognitive Accessibility

Cognitive accessibility focuses on the ease of understanding and interacting with the device for individuals with cognitive disabilities or limitations. Challenges can include complex or ambiguous instructions, overwhelming or confusing interfaces, or lack of clear feedback to indicate successful interactions or errors [24].

3.3.5 Language and Cultural Accessibility

Language and cultural accessibility involve ensuring that the device and its accompanying documentation are available in multiple languages and consider diverse cultural perspectives. Challenges can arise when devices are only available in a limited set of languages or when the content does not account for cultural variations in healthcare practices [45].

3.3.6 User Interface Design

User interface design challenges can affect individuals with various accessibility needs. These challenges can include poorly organized or cluttered interfaces, lack of logical navigation, inconsistent labeling, or insufficient feedback to assist users in understanding and interacting with the device [46], [47].

3.3.7 Training and Support

Adequate training and support are crucial for individuals to effectively use home medical devices. Challenges can arise when the training materials or support resources are not accessible to individuals with disabilities or when the training process does not account for different learning styles or accessibility needs [40].

Addressing these accessibility challenges requires considering universal design principles, conducting user testing with individuals with disabilities, adhering to accessibility guidelines and standards, providing alternative modes of interaction and information presentation, and ensuring comprehensive training and support resources. By addressing these challenges, home medical devices can become more inclusive and usable for individuals with diverse accessibility needs.

3.4 How we can solve accessibility challenges of home medical devices?

To solve accessibility challenges associated with home medical devices, several strategies can be implemented

3.4.1 User-Centered Design

Adopt a user-centered design approach that involves individuals with disabilities or accessibility needs throughout the design and development process. Conduct user research and usability testing with representative users to identify and address specific accessibility challenges [46], [40], [48].

3.4.2 Accessibility Standards and Guidelines

Follow recognized accessibility standards and guidelines, such as the Web Content Accessibility Guidelines (WCAG) or the International Organization for Standardization (ISO) standards for medical devices. These standards provide best practices and requirements for making devices accessible [46], [48].

3.4.3 Physical Design Considerations

Ensure that the physical design of home medical devices considers accessibility needs. This includes features such as larger buttons, tactile markings, adjustable height or reachability, and ergonomic considerations to accommodate users with mobility impairments.

3.4.4 Visual and Auditory Accessibility

Provide alternative modes of information presentation for individuals with visual or hearing impairments. This can include options for larger text sizes, high contrast displays, compatibility with screen readers or magnification software, and visual or vibrating alerts for auditory information [43], [42].

3.4.5 Cognitive Accessibility

Simplify user interfaces, use clear and concise language, and provide visual cues or step-by-step instructions to enhance cognitive accessibility. Avoid overwhelming or complex interfaces and provide feedback that assists users in understanding their interactions and any errors [49].

3.4.6 Multilingual and Culturally Sensitive Design

Consider the linguistic and cultural diversity of users by offering device interfaces and documentation in multiple languages. Ensure that the content is culturally sensitive and adaptable to diverse healthcare practices and beliefs [50].

3.4.7 Training and Support

Provide comprehensive training materials and support resources that are accessible and inclusive. This can include written instructions in plain language, video tutorials with captions and transcripts, and personalized assistance through helplines or online chat.

3.4.8 Collaboration with Accessibility Experts

Collaborate with accessibility experts, disability organizations, and healthcare professionals specializing in accessibility to gain insights and expertise in addressing accessibility challenges specific to home medical devices [51].

3.4.9 Continuous Improvement and Feedback

Regularly gather feedback from users, including individuals with disabilities, to identify areas for improvement and address any ongoing accessibility challenges. Continuously iterate and refine the design based on user feedback and evolving accessibility standards [52], [40].

By implementing these strategies, home medical device manufacturers can effectively address accessibility challenges, create more inclusive products, and ensure that individuals with disabilities or accessibility needs can independently and effectively use these devices for their healthcare needs.

3.5 How artificial intelligence can help to solve accessibility issues of home medical devices?

Artificial intelligence (AI) can play a significant role in solving accessibility issues associated with home medical devices. Here are some ways AI can help

3.5.1 Image and Object Recognition

AI models can be trained to recognize and identify various accessibility features and indicators on home medical devices. For example, AI can identify and label buttons, switches, or display elements, making it easier for individuals with visual impairments or cognitive disabilities to interact with the device [53], [54].

3.5.2 Natural Language Processing (NLP)

NLP techniques can be employed to improve the accessibility of text-based interfaces or documentation associated with home medical devices. AI models can analyze and process text, providing alternative formats such as spoken output, summarized information, or simplified explanations to cater to individuals with reading difficulties or language barriers [55], [56], [57].

3.5.3 Voice Control and Natural Language Interaction

AI-powered voice control systems can enable individuals with mobility or dexterity impairments to interact with home medical devices through voice commands. AI models can interpret and understand spoken instructions, allowing users to control device functions, retrieve information, or receive feedback using speech recognition and natural language understanding [58], [59].

3.5.4 Personalization and Adaptive Interfaces

AI can enable home medical devices to adapt their interfaces based on individual users' preferences, accessibility needs, or cognitive abilities. AI algorithms can learn from user interactions, adjust display settings, or customize user interfaces to optimize accessibility and usability for each user [60], [61], [62], .

3.5.5 Remote Monitoring and Assistance

AI-powered remote monitoring systems can track device usage, detect errors or abnormal behavior, and alert users or caregivers when intervention is required. Additionally, AI chatbots or virtual assistants can provide real-time assistance and support remotely, answering user queries, offering troubleshooting guidance, or providing step-by-step instructions for device operation [63], [64], [65].

Now, I will delve into the motivation and background that led us to the solution of MED-Audit, as well as outline my contributions to this research.

3.6 Background

3.6.1 OT FACT

OT FACT represents a groundbreaking software program capable of transforming the manner in which assessment data is collected, compiled, and reported. It plays a vital role in securing reimbursement from insurance companies for occupational therapy services. It's important to note that OT FACT doesn't supplant occupational therapy evaluation tools; rather, it streamlines the process by integrating data from existing instruments into a comprehensive functional performance profile for each individual [40], [66]. In addition, OT FACT simplifies the task of conveying the "big picture" to others by automatically generating descriptive reports, charts, and graphs that illustrate functional performance. Moreover, its report writing feature effortlessly adapts information to suit clinic-specific or funding agency formats. OT FACT stems from extensive development conducted at the Trace R and D Center, situated at the University of

Wisconsin-Madison. Over the years, this software has undergone frequent reviews and evaluations by occupational therapists nationwide, leading to constant refinement and improvement [67], [68]. OT FACT respects and acknowledges the importance of your professional judgment; instead, it streamlines the process of tracking and reporting the information you've collected in a clear and comprehensive manner. Here's a breakdown of how it operates:

The software conducts an assessment using a vast inventory of over 950 questions. These questions are structured hierarchically, ranging from role function to specific components like neuromuscular functioning. Each question is presented individually to the therapist, such as "Can the client put on clothing independently?" The therapist then responds with one of three options: "total deficit," "partial deficit," or "no deficit."

To optimize efficiency, OT FACT employs a special branching decision tree structure. This means that you won't be required to answer unnecessary questions if it's evident that certain areas don't need assessment. For instance, if you've already indicated "no deficit" in the category of "self-administration of medication," the program won't prompt you for further details [69], [70], [69]. However, if you've chosen "partial deficit," it will present a series of related functions to evaluate, such as "uses correct schedule," "changes medication," and "stores medication properly."

Importance of OT FACT

To facilitate the process of obtaining reimbursement for your occupational therapy services, OT FACT generates reports that highlight the functional outcomes achieved by your clients.

For added convenience, OT FACT 2.0 is portable and can be used in the field. It is compatible with the Apple Macintosh Operating System as well as Microsoft Windows on IBM PCs and their equivalents, including laptops [71].

By using OT FACT, you can streamline and enhance comprehensive functional assessments, making them more efficient and effective.

Investing in OT FACT is a wise decision for your future. Not only is it reasonably priced, but it also offers a comprehensive and customizable program tailored to meet your specific needs.

3.6.2 XFACT

This website serves as a hub for information and resources related to the xFACT software platform, including its original version known as OTFACT, and various assessment applications developed to be compatible with the xFACT platform [1], [72].

The xFACT software suite is a comprehensive tool that operationalizes three key aspects: 1) the formulation, 2) the testing, and 3) the functioning of taxonomies based on the TTSS (Trichotomous Tailored Sub-branching Scoring) system. Dr. Roger O. Smith's research at the Rehabilitation Research Design and Disability R2D2 Center has been dedicated to creating assessments that measure individuals' functional performance and assess the accessibility of environments, computers, learning materials, and products [73], [5].

The xFACT software platform is designed to facilitate evaluators in conducting efficient and convenient comprehensive assessments. It presents xFACT-based taxonomies in a hierarchical format and allows users to score these taxonomies [73].

The xFACT software suite comprises three main components: the Validator, Relevator, and Utility. Each of these components is conceptualized, if not fully operationalized,

Figure 3.1: OT FACT application [1]

to function within the xFACT platform, utilizing the principles of Trichotomous Tailored Sub-branching Scoring (TTSS) and the Taxonomy of Categories.

The roots of xFACT can be traced back to OTFACT, a software package that originated in the field of occupational therapy and was developed during the 1980s and 1990s. The initial support for OTFACT came from The American Occupational Therapy Foundation and Apple Computer, Inc [1], [74].

Development of the xFACT Platform: In the early 1990s, the manual version of OTFACT underwent computerization, giving rise to the current xFACT software platform. Recently, significant enhancements have been made to the xFACT software platform to cater to the needs of the R2D2 Center and other entities involved in creating TTSS-based taxonomies. These advancements aim to address the growing demand for more comprehensive and efficient assessments of individuals' functional performance, assistive technologies, and universal design initiatives aimed at improving accessibility and active participation in the community for individuals with disabilities [1], .

Throughout more than two decades, the R2D2 Center has developed numerous taxonomies. The process of validating and ensuring the usability of these newly created assessments has driven the evolution of the xFACT software platform. Presently, apart from facilitating functional assessments, the xFACT software suite also includes the xFACT Content Validator, the xFACT Relevator, and an xFACT Taxonomy Editor, which collectively support the development of xFACT taxonomies.

The Bibliography section encompasses a comprehensive collection of all OTFACT and xFACT-based taxonomies, along with theses, dissertations, projects, publications, and presentations associated with OTFACT and xFACT-based initiatives. Additionally, it contains references detailing the origin, development, and utilization of the xFACT software platform [72], [73].

Trichotomous Tailored Sub-branching Scoring (TTSS): TTSS, utilized by xFACT-based applications, employs a distinctive trichotomous scale to score items within the taxonomy. This scale is characterized by three cardinal features: 1) trichotomous, 2) tailored, and 3) sub-branching, rendering it an efficient and distinct approach for conducting comprehensive assessments in a relatively shorter timeframe [71], [6]. Here are concise explanations of these three features:

Trichotomous Scoring: Every item in the taxonomy is scored using a trichotomous scale, represented by values 0, 1, and 2. A score of 0 is assigned when none of the criteria for a specific question are met, while a score of 2 indicates that a client/subject fulfills all the criteria for that category. Of particular significance is the score of 1, which is given when some criteria are met for an item, but others remain unaccomplished (Smith, 1999). Further insight into the importance of these scores is detailed in section 3. Tailored: Alongside the three responses, two additional options, "not-applicable" and "not examined," are provided for irrelevant questions. This customization enables the assessment to be relevant to individuals within their unique contexts. Any items marked as not applicable or not examined are omitted from the total scores, resulting in a tailored assessment that aligns with an individual's specific needs and circumstances [71], [1], [6]. Sub-branching: A distinctive aspect of TTSS-based taxonomies is sub-branching, allowing for both detailed analysis and efficient scoring. If an item receives a score of 0 or 2, the TTSS process moves to the next branch of the same level in the taxonomy. However, if a score of 1 is given, the taxonomy opens sub-branches, permitting a more detailed analysis of the assessment [6], [71].

Figure 3.2: XFACT application [1]

MED-AUDIT: The Medical Equipment Device – Accessibility and Universal Design Information Tool Numerous iterations of the MED-AUDIT have been created, and here we present the initial implementation and testing of the MED-AUDIT, designed to serve as a medical equipment and device evaluation and information system. Its primary objective is to ensure equitable access to healthcare for individuals, encompassing both people with disabilities and older adults [75], [76].

The main purpose behind designing the MED-AUDIT was to assess and quantify accessibility for people with disabilities, aiming to reduce healthcare disparities among medical device users with disabilities. The five specific design objectives for the MED-AUDIT:

To provide informative reports about the accessibility of medical devices to designers and the general public, especially those who may not be familiar with the unique needs of people with disabilities [1], [77]. To ensure efficiency in the questioning process while evaluating the accessibility of a product, even though there might be numerous questions that could be asked. To produce MED-AUDIT scores that offer both an overall view of how universally designed a product is for all potential users and specific insights for individuals with disabilities regarding the product's accessibility tailored to their unique needs [76], [78]. To generate quantitative output from the assessment to enable comparison of device designs. To ensure that the MED-AUDIT scores are reliable and valid from a psychometric standpoint. The integrated MED-AUDIT scores rely on two primary data sources. The first source comes from designers or other product assessors who assess the tasks required and features included in a device. The second source involves importing data from a knowledge base containing two matrices previously populated by experts. These matrices predict relationships between a) product features and user impairments and b) product features and tasks [5], [6], [79]. An algorithm combines these data sources and effectively weighs the assessor's responses to produce MED-AUDIT scores, indicating the level of accessibility of the evaluated medical device on a scale of 0-100percent. Question Domains: The MED-AUDIT was designed with two primary question sections: (I) Procedures-Task Analysis and (II) Device Features. The rationale behind this structure was to comprehensively assess the accessibility of medical devices by considering both the tasks required for device use and the accessibility features incorporated into the device design [77].

The first domain, Procedures-Task Analysis, focuses on identifying the tasks that a device user must perform in order to use the device effectively. The relevance of certain tasks is crucial in scoring the accessibility of a device. For instance, if a device doesn't require users to position themselves on it (e.g., an auditory alarm), tasks related to transferring onto the device become irrelevant. On the other hand, specific tasks may be critical in measuring device accessibility. The inclusion of relevant tasks is essential to accurately evaluate accessibility.

The second domain of questions revolves around the accessibility features present in the device being assessed. The presence of accessible features significantly impacts the generated accessibility scores. As a result, some tasks required for device use may also necessitate accessible features. For example, in the case of an auditory alarm, an essential task would be to recognize the sound. To receive the highest accessibility rating, the device would need to include visual and tactile alarm outputs as well.

The experts are from two central MED-AUDIT scoring domains, displaying the key components. The current question taxonomy draft contains 1158 distinct questions, consisting of 177 task requirements and 981 device features. These questions are thoughtfully organized in a hierarchical outline, encompassing 33 major categories: 10 for task requirements and 23 for device features [1], [77]. PROCEDURES-TASK ANALYSIS Prepare for device use Select appropriate device Familiarize self with device Familiarize self with person Match device to situation Understand device use Understand general procedure Understand component procedure Understand controls Understand display info Receive training to use the device Position device-prep for use Locate device Detect orientation of the device Approach- move to device DEVICE FEATURES Overall Device Features Parts that req. assembly and disassembly Easy assembly Infrequent assembly Few steps required Easy disassembly Infrequent disassembly Displays Monitors/screen displays Enhanced contrast Screen Size Brightness contrast Contrast adjustment Brightness adjustment Brightness coding

Software and Question Branching: The MED-AUDIT question domains, procedures-task analysis, and device features are integrated into the software using the trichotomous tailored subbranching scoring structure (TTSS). This efficient question branching method eliminates irrelevant questions from the assessment process. The TTSS employs a trichotomous response format for each question, where 2 indicates no issues, 0 signifies total problems, and 1 denotes partial problems [73], [6].

When a rater responds with a 2 or 0 to a MED-AUDIT question, the TTSS software progresses to the next major category of questions, skipping the sub-level detailed questions in between. On the other hand, if a rater responds with a 1 to a question, the TTSS breaks down the category into more detailed subcategories, prompting the rater for further information. This trichotomous scoring approach offers several advantages:

It simplifies cognitive processing, leading to increased reliability and faster response scoring. It enhances efficiency by only asking detailed questions when relevant, allowing for potential inclusion of more detailed questions as irrelevant ones are omitted. It provides flexibility in adjusting the verbal anchors accompanying the response sets as needed, enabling intentional variations in constructs (e.g., requires tasks, somewhat requires tasks, does not require tasks; includes feature, somewhat includes feature, does not include feature) (Smith, 1993, 1994, 1995, 2002).

Impairment Categories: To establish the foundation for generating MED-AUDIT scores, an extensive review of the literature (refer to: MED-AUDIT Impairment Categories: Working Towards Mapping AMI Usability) was conducted. This review involved identifying the most suitable impairment-related categorization schemes. Several sources were consulted, including studies by Barbotte, Guillemin, Chau, and the Lorhandicap Group (2001); the Center for Rehabilitation Technology (2001); Pizur-Barnekow, Lemke, Smith, Winter, and Mendonca (2005); the United States Census Bureau (2004); the United States Department of Health and Human Services (2004); Vanderheiden, and Vanderheiden (1991); and the World Health Organization (2002).

Based on this thorough examination, a set of thirteen impairments, along with their corresponding definitions, was formulated for the MED-AUDIT. These impairment categories are designed to be mutually exclusive and comprehensive, providing a comprehensive framework for assessing device accessibility. The set of thirteen impairments includes the following: Hard of hearing Deaf Vision limitation Blind Expressive communication impairment Comprehension disorders Other cognitive disorders Mental and behavioral impairment Sensitivity impairment Lower limb impairment Upper limb impairment Head, neck, and trunk impairment Systemic body impairment These impairments serve as the basis for generating scores related to device accessibility in the MED-AUDIT evaluation process. Accessibility Expert Knowledge Matrices: The expert-mapped matrices are an integral part of the MED-AUDIT software algorithm, providing prior likelihoods for the simple Bayes model (Birnbaum, 1999; Gustafson, Cats-Baril, and Alemi, 1992; Malakoff, 1999). These matrices play a crucial role in generating overall accessibility scores for medical devices by assigning relative weightings to question categories.

There are two distinct matrices that correlate within the system:

The first matrix links the tasks involved in using the medical device with accessibility features necessary to complete those tasks. The second matrix connects medical device features that enhance accessibility for specific user impairment groups. The correlation between device features and user impairments establishes the vital link for generating comprehensive device accessibility scores.

The data contained in these expert knowledge matrices, along with the data provided by the rater for a specific device, allows the MED-AUDIT to generate accessibility scores for various user impairment types. The algorithm employed for this process is detailed in the subsequent section.

Excerpts from both matrices can be found in Tables 2 and 3 below, showcasing their essential components.

MED-AUDIT Accessibility Scoring Algorithm: The MED-AUDIT scoring underwent its initial development by conceptualizing the logic and scoring requirements for the algorithm, as illustrated in Figure 2 below. The tool's domains were established, encompassing sections for device features and task requirements. Conceptualization of expert matrices occurred, involving features required for tasks and features needed for various impairments. The basic operations of the scoring modality were also defined, determining how the overall score would increase or decrease based on the type of information provided for each specific device. Figure 2 displays various scoring cases, including a maximum mathematical relationship of +8, a minimum mathematical relationship of -8, intermediate cases of +4, +2, -2, and -4, as well as a case of 0.

Equation 1, used during the pilot scoring algorithm in the initial implementation of the MED-AUDIT (initially developed in Fortran), involves four product terms to generate overall accessibility and usability scores:

Expert scored device feature requirement for a task [xe-dT] Expert scored device feature requirement for user impairment [xe-iD] Rater scored device feature presence on the device [xr-d] Rater scored task requirement for device use [xr-T] When raters score a device feature presence as 2, the scoring element is positive. In such cases, if the feature is needed, the score will be positive since the required feature is present. When raters score device feature presence as 1, the scoring element is disregarded, resulting in a zero score. This means that whether the feature is needed or not, the score will not be affected positively or negatively because the required feature may or may not be present. When raters score device feature presence as 0, the scoring element is negative. In such cases, if the feature is needed, the score will be negative since the required feature is not present.

Pilot testing of this approach was conducted using an improved MED-AUDIT interface that employed case-specific logic to generate accessibility and usability scores for different medical devices.

3.6.3 Methodology

To live independently is one of the major challenges for people with disabilities (PwD). A critical object of independently living is the ability to choose and purchase consumer products for daily life, including medical products. Moreover, there is limited to no information about the accessibility of medical products to assist PwD to make informed decisions.

Research Challenges: Addressing the complexities of people with disabilities presents significant variability.

Numerous medical devices serve diverse functions, leading to a wide range of requirements.

Universal design is intricate, with some features being essential for accessibility while others primarily focus on usability.

Obtaining reliability and validity in assessments could prove challenging due to the complexities involved.

Inaccessible medical products prevent PwD from being treated in a timely manner, leading to critical healthcare disparities. In addition, COVID-19 pandemic focuses on this need like never before [4]. The U.S. Patient Protection and Affordable Care Act advanced a mandate the accessible medical devices (7) and the U.S. Access Board developed accessibility guidelines for specific diagnostic equipment (4) [2, 3]. However, there are no strategies to provide accessibility information to PwD or care partners to help them make informed product choices. A number of research highlight the significant difficulties and disparities that PwD experience due to medical device inaccessibility (1-14). One major problem is the inability to get accessibility information and the lack of personalization of information to allow PwD for matching their needs to available devices. Moreover, accessibility information system has some major challenges in personalizing information, which is ripe for Artificial Intelligence (AI) solutions [20, 25]. This research developed a prototype to prove the concept. The application is named MED-AUDIT. The MED- AUDIT application provides PwD with personalized accessibility information (PAI) about medical devices, optimizing it using machine learning (ML), and scoring devices based on a computational equation. Successful implementation of this research project can impact not only enhanced accessibility in medical device design but will also provide a standard strategy for PAI that can be applied to diverse products and environments.

The MED-AUDIT has two major question sections: (I) Procedures-Task Analysis and (II) Device Features [77]. To determine the accessibility of medical devices, it is essential to know the tasks that a device user is required to perform in order to use the device as well as the accessibility features present in the device design. Related tasks are important to measure the accessibility of a device. Certain tasks are irrelevant for scoring accessibility and other tasks are critical for measuring device accessibility. The second domain of questions focuses on the accessibility features of the device being rated. These two domains relate as some tasks required by a device. In the example of an auditory alarm, an essential task would be to recognize the sound. The current question taxonomy draft includes 1158 distinct questions, with 177 task requirements and 981 device features. The questions are arranged in a hierarchal outline that includes 33 major categories: 10 for the task.

3.7 What ethical considerations should be taken into account when using AI for home Medical devices accessibility measurement, such as privacy, bias mitigation, and transparency in decision-making processes?

When using AI for home medical device accessibility measurement, it is important to consider and address several ethical considerations, including

3.7.1 Privacy

Ensure that the data collected and processed by AI systems for home medical device accessibility measurement is handled with strict privacy measures. Safeguard personal health information and adhere to relevant privacy regulations. Minimize the collection of personally identifiable information (PII) and implement robust security measures to protect user data from unauthorized access or breaches.

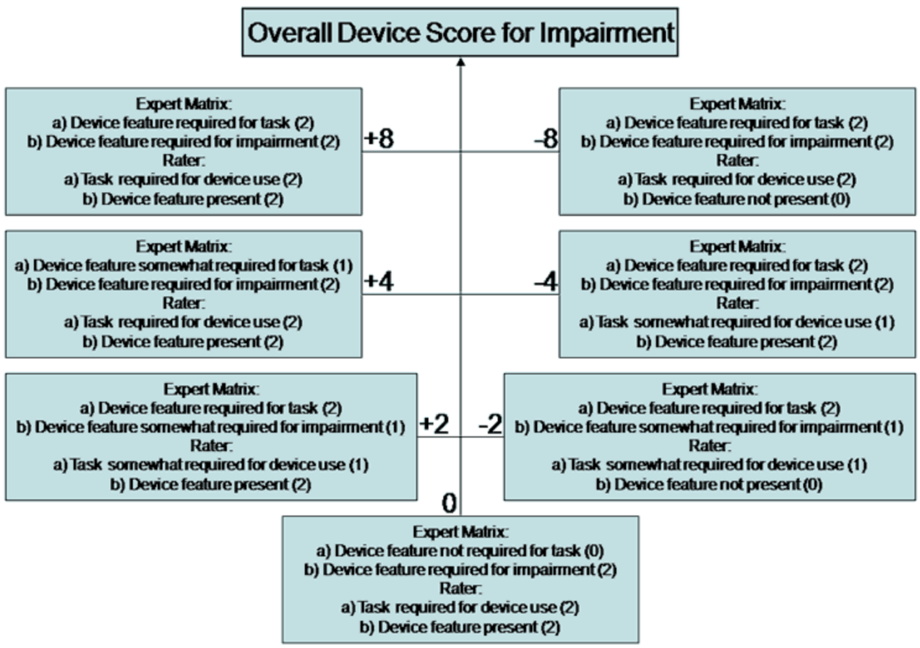


Figure 3.3: Scoring Impairment Flow [1]

	Hard Of Hearing	Deaf	Low Vision	Blind	Expressive Communication	Comprehension Disorders	Other Cognitive Disorders	Behavioral Impairment	Sensitivity Impairment	Lower Limb Impairment	Upper Limb Impairment	Head, Neck And Trunk Impairment	Systemic Body Impairment
Manual Inflate Monitor	0	47	46	53	45	45	54	44	48	37	44	41	39
Automatic Wrist Monitor	72	71	76	74	67	69	80	66	69	66	69	66	67
Deluxe Automatic Arm Monitor	75	75	85	73	69	72	87	69	75	66	72	71	68
Deluxe Automatic Wrist Monitor	89	87	98	88	82	85	95	83	87	91	90	88	96

Figure 3.4: Different devices impairment scoring

3.7.2 Informed Consent

Obtain informed consent from individuals before collecting and using their data for accessibility measurement purposes. Clearly communicate the purpose, methods, and potential risks associated with data collection, and provide options for individuals to opt-in or opt-out of data sharing.

OldRange = (OldMax - OldMin)
NewRange = (NewMax - NewMin)
NewValue = (((OldValue - OldMin) * NewRange) / OldRange) + NewMin

Figure 3.5: Chart view of medical device scoring based on 13 impairments group and normalize algorithm

3.7.3 Bias Mitigation

Address potential biases in AI systems used for home medical device accessibility measurement. Biases can arise from biased training data, algorithmic biases, or inherent limitations of the system. Regularly evaluate and mitigate biases to ensure fair and accurate accessibility assessments for individuals with diverse disabilities or accessibility needs.

3.7.4 Transparency and Explainability

AI systems used for home medical device accessibility measurement should be transparent and explainable. Users should have visibility into how the system makes decisions and assessments regarding accessibility. Provide clear explanations of how data is collected, processed, and used to generate accessibility measurements. This transparency helps build trust and enables users to understand and verify the results.

3.7.5 Accountability

Establish clear lines of accountability for the AI system's performance and outcomes. Define roles and responsibilities for system developers, operators, and stakeholders to ensure appropriate oversight, auditing, and addressing of any issues or concerns that may arise.

3.7.6 User Autonomy and Control

Prioritize user autonomy and control over their own health data and accessibility information. Allow individuals to have control over the data collected, its use, and the ability to modify or delete their data. Respect user preferences and decisions regarding data sharing and system usage.

3.7.7 Accessibility and Inclusivity

Ensure that the AI system itself is accessible and usable by individuals with disabilities or accessibility needs. Consider accessibility standards and guidelines during the design and development process to make the AI system inclusive and usable for all users.

3.7.8 Ongoing Evaluation and Improvement

Continuously evaluate the performance, accuracy, and impact of the AI system for home medical device accessibility measurement. Incorporate feedback from users, healthcare professionals, and stakeholders to identify and address any ethical concerns, biases, or limitations of the system. Strive for continuous improvement and iterative development to enhance the ethical and inclusive use of AI for home medical device accessibility measurement. By considering these ethical considerations, AI-based systems for home medical device accessibility measurement can promote privacy, fairness, transparency, user autonomy, and inclusivity while minimizing potential risks and biases associated with data privacy and decision-making processes.

These research questions can guide the development and exploration of AI-based solutions that leverage machine learning, computer vision, natural language processing, and data analytics to improve the accessibility assessment and evaluation of private homes.

3.7.9 AI based improvement on Existing MED-AUDIT application

Case 1: No medical device accessibility information (NO MED-Audit App) + No user information (NO MED-Audit scoring).

Case 2: No medical device accessibility information (NO MED-Audit App) + some user information (MED-Audit scoring) or No medical device accessibility information (NO MED-Audit App) + detail user information (person-based MED-Audit scoring).

Case 3:Some medical device accessibility information (MED-Audit App) + no user information.

Case 4: Some medical device accessibility information (MED-Audit app) + some user information (MED-Audit scoring) + detail user information (person-based MED-Audit scoring).

Case 5: Details medical device accessibility information + No user information (MED-Audit scoring) or user profile.

Case 6: Detail medical device accessibility information + some user information (MED-Audit scoring) + detail user information (person-based MED-Audit scoring).

In conclusion, the novel assessment tool for home medical device assessment and rating, consisting of comprehensive questionnaires for disability-specific products, will have a significant impact on the rehabilitation system by enhancing the existing system and promoting improvement for independent living. The next scetion we will discuss AccessRating for building based on this evaluation concept.

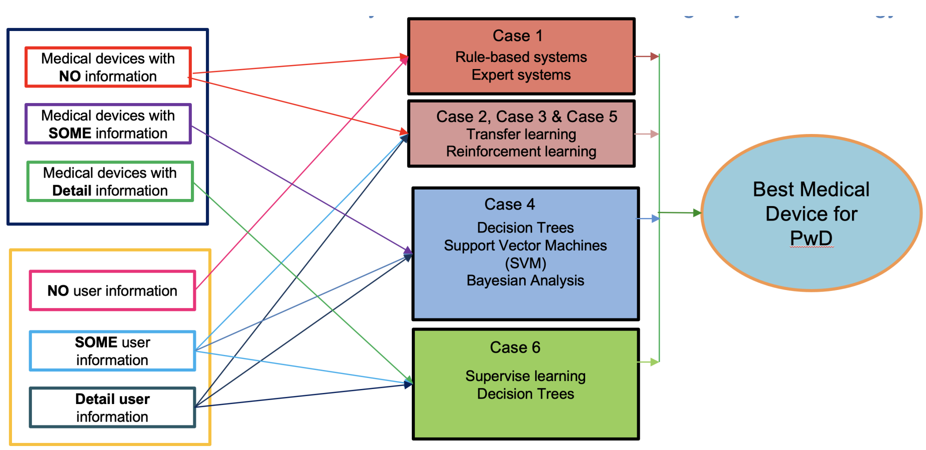


Figure 3.6: AI based analysis for decide best medical device

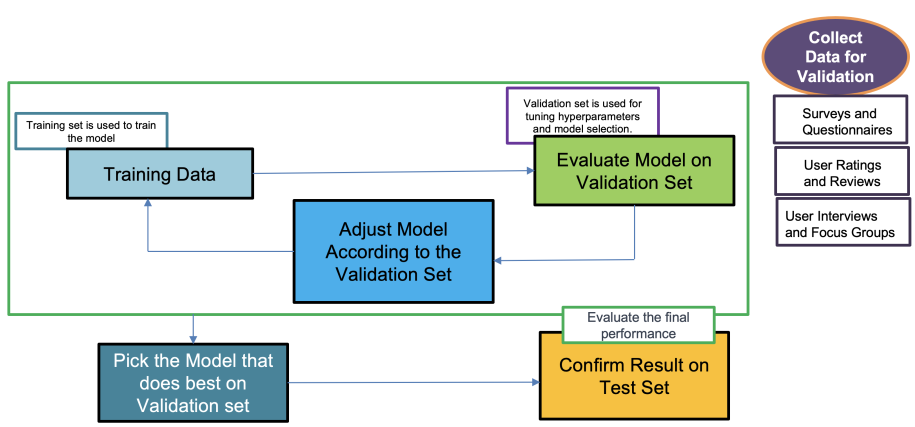


Figure 3.7: Improving AI models using model validation

Chapter 4
Enhance the Accuracy of Accessibility Evaluations of Public Buildings

Ensuring inclusivity in public buildings is essential for the full participation of all individuals, especially those with disabilities. The Americans with Disabilities Act (ADA), enacted in 1990 and updated in 2010 (ADA-ABA), has made significant strides in granting access to previously inaccessible public buildings for thousands of people with disabilities [1]. However, despite these efforts, individuals with disabilities still encounter barriers that prevent their complete community engagement due to inaccessible environments [33]. To empower individuals with disabilities and foster their active involvement in society, it is crucial to conduct thorough assessments of the accessibility of public buildings and address any obstacles that hinder their participation. Unfortunately, there is currently limited availability of comprehensive, reliable, and valid assessment tools for evaluating and analyzing accessibility barriers in public buildings. The existing tools can be time-consuming to use [80]. Furthermore, while some accessibility assessment tools have been developed, they primarily focus on the physical aspects of accessibility and often overlook the specific needs and requirements of individuals with cognitive, visual, or auditory impairments.

This chapter begins with a theoretical discussion on the fundamental concepts of building accessibility, emphasizing the challenges associated with measuring accessibility. Subsequently, we present our methodology designed to address these challenges in accessibility measurement. Furthermore, we delve into an exploration of popular AI models and their potential to enhance existing accessibility measurement methods.

4.1 What is building accessibility?

Building structure accessibility refers to the design and construction of buildings in a way that allows people with disabilities or mobility limitations to access and use them comfortably and independently. It involves creating an inclusive environment that accommodates individuals with diverse needs, ensuring equal access and participation for everyone. Key aspects of building structure accessibility include:

Entrance and Exits: Designing accessible entrances and exit with features such as ramps, elevators, and automatic doors to facilitate entry and exit for individuals with mobility devices like wheelchairs or walkers.

Pathways and Circulation: Providing clear and accessible pathways throughout the building, including hallways, corridors, and walkways, without obstacles or obstructions. Incorporating features like wide doorways, appropriate signage, and tactile indicators for individuals with visual impairments.

Restrooms: Constructing restrooms that are accessible to people with disabilities, including features like grab bars, properly positioned sinks, toilets with adequate space, and clear floor space for maneuverability. Parking Facilities: Designating accessible parking spaces close to the building entrance, providing sufficient width for wheelchair access and appropriate signage.

Elevators and Lifts: Installing elevators or lifts to connect different levels of the building, ensuring they are spacious, equipped with braille buttons, and have audible announcements for people with visual or hearing impairments.

Communication and Signage: Incorporating clear signage and way finding systems with visual, tactile, and audible elements to assist individuals with disabilities in navigating the building.

Lighting and Acoustics: Ensuring appropriate lighting levels to assist people with visual impairments and designing spaces to minimize reverberation and echo for individuals with hearing impairments.

Emergency Evacuation: Developing effective emergency evacuation plans that consider the needs of individuals with disabilities, including accessible emergency exits, evacuation chairs, and communication systems.

Building structure accessibility is essential to promote inclusively, equal opportunities, and independence for individuals with disabilities. By implementing accessible design principles, architects, engineers, and builders can create spaces that accommodate the needs of all people, regardless of their abilities or limitations [81], [82].

4.2 What are the different types building accessibility?

Building accessibility encompasses several distinct types that address specific areas and aspects of accessibility [83], [84]. Below are some widely recognized categories:

4.2.1 Physical Accessibility

Physical accessibility in the context of public buildings entails the implementation of design elements and features that facilitate the independent and safe navigation and utilization of the building by individuals with mobility impairments. The objective is to establish an inclusive environment that caters to the needs of people with disabilities, ensuring their unobstructed entry, exit, and movement throughout the premises. This includes features such as ramps, elevators, wide doorways, accessible parking spaces, and barrier-free pathways [85].

4.2.2 Visual Accessibility

Visual accessibility strives to offer inclusive provisions for individuals with visual impairments or low vision. This entails the implementation of various features, such as braille signage, tactile indicators incorporated into floors and walls, high contrast markings, and suitable lighting levels that enhance visibility [43], [42].

4.2.3 Auditory Accessibility

Auditory accessibility focuses on meeting the requirements of individuals with hearing impairments or deafness. This encompasses the provision of assistive listening systems, visual alarms and notifications, and the establishment of suitable acoustics that reduce background noise and reverberation [86].

4.2.4 Cognitive Accessibility

Cognitive accessibility aims to establish an environment that is easily comprehensible and navigable for individuals with cognitive disabilities, learning disabilities, or neurodiverse conditions. This can be achieved through the implementation of clear signage, straightforward and consistent wayfinding systems, visual cues, and the provision of accessible information presented in plain language [85].

4.2.5 Communication Accessibility

The objective of communication accessibility is to facilitate effective communication for individuals with speech disabilities, language barriers, or communication disorders. This entails offering alternative communication methods, which may include assistive devices, accessible communication boards, or sign language interpretation services. The goal is to enable seamless and inclusive communication for individuals facing such challenges [87], [88].

4.2.6 Technological Accessibility

Technological accessibility encompasses the integration of accessible technology and digital systems within buildings. This entails incorporating features such as accessible websites and applications, touchless controls, captioning and transcription services, and compatibility with assistive technology [89].

It is crucial to recognize that these various types of accessibility are interconnected, and it is essential for buildings to incorporate multiple aspects to ensure comprehensive accessibility for all individuals. By considering these different types of accessibility, architects, designers, and building owners can create inclusive spaces that cater to the diverse needs of people with disabilities [90], [91], [92], [93].

4.3 Different types building accessibility based on privacy

When contemplating the aspect of building accessibility concerning privacy, the emphasis lies on guaranteeing equal access to private spaces for individuals with disabilities while preserving their dignity and confidentiality. Below are several elements pertaining to building accessibility that are associated with privacy considerations [83], [88].

Accessible Restrooms: Ensuring accessibility in restroom facilities is essential to meet the needs of individuals with disabilities. This includes the provision of accessible stalls with features such as grab bars, sufficient space for maneuvering, and privacy elements like doors and partitions that guarantee confidentiality.

Changing Rooms and Fitting Areas: Incorporating accessibility features into changing rooms and fitting areas within stores, gyms, or healthcare facilities involves thoughtful design considerations. These features encompass providing ample space to accommodate mobility devices, incorporating privacy curtains or partitions, and ensuring accessible seating options.

Private Offices and Workstations: Ensuring that private offices, cubicles, or workstations in a workplace are designed with accessibility in mind, providing adequate space for maneuverability, adjustable desks or work surfaces, and privacy considerations for individuals who may require assistive devices or accommodations.

Examination Rooms: Creating accessible examination rooms in healthcare facilities that offer privacy features such as doors, curtains, or partitions, as well as sufficient space for maneuverability and accessibility for medical equipment.

Confidentiality in Common Spaces: Implementing measures to maintain privacy and confidentiality in shared spaces such as waiting areas, meeting rooms, or common lounges. This may involve adequate spacing between seating, acoustic treatments to minimize sound transmission, and visual barriers to ensure confidentiality during conversations or meetings.

Accessible Sleeping Quarters: In environments such as hotels, dormitories, or healthcare facilities, it is important to offer accessible sleeping quarters that cater to the needs of individuals with disabilities. These quarters should include features such as accessible beds, sufficient turning space, accessible storage options, and appropriate measures to ensure privacy.

The objective of incorporating privacy considerations in building accessibility is to establish an inclusive environment where individuals with disabilities can access private spaces and services while maintaining their dignity and confidentiality. By integrating features that address privacy concerns, buildings can ensure equal access and provide a respectful experience for all individuals, regardless of their abilities or disabilities [91].

4.4 What is subjective and objective accessibility of public building?

4.4.1 Objective Accessibility (Public Building)

The objective accessibility of a public building pertains to the tangible and quantifiable aspects of its design and characteristics that facilitate the entry and movement of individuals with disabilities. It encompasses adhering to defined accessibility codes or laws, as well as meeting specific standards and guidelines. Objective accessibility encompasses features like ramps, elevators, designated parking spaces, signage, restrooms, door widths, and other physical attributes that guarantee compliance with accessibility regulations. Evaluating objective accessibility involves appraising the building against predetermined criteria to ascertain whether it satisfies the minimum requirements for accessibility [94], [95].

4.4.2 Subjective Accessibility (Public Building)

The subjective accessibility of a public building takes into consideration the individual experiences, perceptions, and comfort of people with disabilities as they interact with and utilize the building. It recognizes the diverse needs, preferences, and overall user experience of each individual. Subjective accessibility entails evaluating factors like usability, convenience, inclusivity, availability of assistance, and overall satisfaction with the building's accessibility features. This viewpoint acknowledges that accessibility goes beyond meeting objective standards and regulations, emphasizing the importance of creating a positive and inclusive experience for individuals with disabilities within the public building [48], [96], [95].

The objective accessibility of a public building focuses on meeting physical accessibility standards and guidelines, while subjective accessibility considers the personal experiences and satisfaction of individuals with disabilities. Both perspectives are essential in evaluating and improving the accessibility of public buildings, ensuring compliance with regulations and providing a positive and inclusive environment for all users [48], [95], [94].

4.5 What is accessibility measurement?

The accessibility measurement in a public building involves assessing and quantifying the degree of access and usability available to individuals with disabilities [97], [98]. This process entails evaluating different aspects of the building's design, features, and services to gauge how well it caters to the needs of people with disabilities. Accessibility measurement encompasses both objective criteria, such as adherence to accessibility codes, standards, and regulations, and subjective factors, including the user experience and satisfaction of individuals with disabilities. The purpose of this measurement is to gain an accurate and comprehensive understanding of the building's accessibility, identifying areas that may require improvement and ensuring inclusivity for all users [86], [99], [100], . Here are some key considerations in measuring accessibility:

4.5.1 Physical Accessibility

The focus lies in evaluating whether the building possesses attributes that empower individuals with mobility impairments to enter, navigate, and utilize the facilities autonomously. This assessment encompasses the evaluation of elements such as ramps, elevators, spacious doorways, designated parking spaces, and accessible restrooms.

4.5.2 Navigation and Wayfinding

It involves evaluating the building's signage, floor plans, clear paths, and visual cues to ensure people with visual impairments or cognitive disabilities can easily find their way within the building. Tactile indicators, braille signage, and audible cues may be necessary to assist individuals with visual impairments.

4.5.3 Communication Accessibility

This measures entails assessing the building's signage, floor plans, unobstructed pathways, and visual cues to guarantee that individuals with visual impairments or cognitive disabilities can effortlessly navigate the premises. To assist individuals with visual impairments, tactile indicators, braille signage, and audible cues may be required to provide necessary guidance and information..

4.5.4 Assistive Technology

Assistive technology, as it relates to measuring the accessibility of a public building, encompasses devices, tools, or systems specifically designed to aid individuals with disabilities in accessing and utilizing the premises. These technologies are intended to improve accessibility and promote independence for people with disabilities.

Within the context of accessibility measurement, examples of assistive technology include: i)Wheelchair ramps and lifts: These assistive devices enable individuals using wheelchairs or mobility aids to access different levels of the building. ii) Elevators and lifts: These technologies facilitate the movement of individuals with mobility impairments between various floors within the building. iii) Tactile indicators and braille signage: These features provide tactile and braille information respectively, aiding individuals with visual impairments in navigating the building and locating specific areas. iv) Audio and visual cues: These technologies utilize audible or visual signals to provide guidance and information to individuals with hearing impairments or cognitive disabilities. v) Automatic doors and switches: These assistive technologies simplify access for individuals with mobility impairments by automatically opening doors or activating switches with minimal physical effort [101]. vi) Assistive listening systems: These systems transmit amplified sound directly to hearing aids or assistive listening devices, improving communication for individuals with hearing impairments. vii) Augmented reality or mobile applications: These technologies offer real-time navigation, visual and auditory assistance, and personalized support to individuals with diverse disabilities [102], [103], [104], [7].

Assistive technology plays a critical role in evaluating and enhancing the accessibility of public buildings, ensuring that individuals with disabilities can overcome barriers and independently and comfortably access the building's facilities.

4.5.5 Emergency Evacuation

The evaluation involves assessing the building's emergency evacuation procedures to guarantee their inclusivity towards individuals with disabilities. This assessment includes considering factors such as accessible evacuation routes, the availability of evacuation chairs, designated refuge areas, and ensuring that staff are adequately trained in assisting people with disabilities during emergencies.

4.5.6 Universal Design

Considering whether the building's design and features adhere to universal design principles, which strive to create environments that are accessible and functional for individuals with diverse abilities and disabilities [36], [8], [30].

The measurements of accessibility can differ depending on regional building codes, accessibility guidelines (such as the ADA in the United States), and the specific requirements of the target population. Organizations frequently carry out accessibility audits or assessments to identify barriers and implement enhancements that improve accessibility in public buildings.

4.6 Why accessibility measure of a public building is important?

The accessibility of public buildings holds great significance for society as a whole, particularly for individuals with disabilities [11]. Accessibility pertains to the opportunity for an individual or a specific group to engage in particular activities at a given location. In 1990, the Americans with Disabilities Act (ADA) was established, and it was later updated in 2010 (ADA-ABA), enabling numerous people with disabilities to access public buildings that were previously inaccessible [11], [7]. However, despite societal and community efforts, inaccessible environments continue to hinder the full participation of individuals with disabilities in society. It is crucial for people with disabilities to have the ability to interact with their communities and actively engage in society by assessing the accessibility of public facilities. The followings are some vital point why accessibility measurement of a public building is important:

4.6.1 Equal Access

Public buildings are designed to be inclusive spaces, providing equal access to individuals of all abilities and disabilities. By implementing accessibility measures, these buildings ensure that everyone can freely utilize the services, facilities, and opportunities offered within them. Such measures promote inclusivity and help prevent any form of discrimination based on disabilities.

4.6.2 Legal and Regulatory Compliance

Numerous nations have implemented laws and regulations to enforce accessibility standards for public buildings. In the United States, for instance, the Americans with Disabilities Act (ADA) establishes guidelines for accessibility in public buildings. Complying with these laws and regulations is crucial to avoid legal repercussions and penalties. It showcases a dedication to ensuring equitable access for individuals with disabilities.

4.6.3 Social Responsibility

Public buildings play a vital role in serving the entire community. By implementing accessibility measures within these buildings, a commitment to social responsibility is demonstrated, ensuring that all members of the community can actively participate in society. This commitment fosters a more inclusive and compassionate society that values diversity and upholds the rights of individuals with disabilities.

4.6.4 Economic Impact

The accessibility in public buildings can generate positive economic outcomes. By offering access to a wider customer base, accessible public buildings attract a larger number of visitors, customers, and users. Consequently, this can lead to increased revenue and expanded business prospects. Moreover, an environment that is accessible fosters a favorable reputation and may encourage repeat visits or continued patronage.

4.6.5 Safety and Emergency Preparedness

Accessibility measures in public buildings also contribute to safety and emergency preparedness. They ensure that individuals with disabilities can safely evacuate during emergencies and have access to emergency services. This is crucial for the well-being and protection of all occupants of a public building.

4.6.6 Universal Design Principles

Incorporating accessibility measures in public buildings frequently aligns with the principles of universal design. Universal design aims to create environments that are usable by individuals of various abilities and age groups. By integrating accessibility features, public buildings can cater to a wide range of individuals, including older adults, parents with strollers, and individuals with temporary disabilities. This approach ensures that the built environment is inclusive and accommodating to diverse users [105], [106].

In summary, the accessibility measure of a public building is important because it promotes equal access, ensures legal compliance, demonstrates social responsibility, has economic benefits, enhances safety, and aligns with universal design principles. By creating accessible public spaces, we foster a more inclusive and equitable society for everyone. Finding relevant, trustworthy, and complete assessments for assessing and analyzing accessibility barriers in public buildings is still difficult and time-consuming [107], [108], [109]. In addition, although many accessibility evaluation tools have been created, they mostly focus on the physical component of accessibility rather than considering the needs of people with cognitive, visual, or hearing impairments [110], .

4.7 Challenges of accessibility measurement

For public buildings (e.g., hospitals, schools, museums, etc.), even though there is substantial literature on accessibility measurements, it is far from clear what constitutes the optimal measure of accessibility [99], [111], [112], [1]. The issue is that an accessibility measure should only be used as a performance indicator if it corresponds to how community members with disabilities see and value their environment. A major challenge in defining and implementing building accessibility measurements is that the complexity of the environment being measured depends on the quality of the user experience and the quality of the processes performed to deliver that experience [2], [4]. For example, the standard for accessibility measures is based on the ADA guidelines. Often these questions are too general to capture individual needs [6], [113]. As such, measuring accessibility can take a lot of time and effort and inevitably involves a degree of subjectivity that must be carefully controlled for the measurements to be reliable and meaningful [114], [115]. The followings are the list of accessibility measurement challenges and examples impacting the acquisition of accessibility information.

4.7.1 Importance of individual questions

Assessment question sets do not weigh the importance of individual questions. It is unknown whether the measurement follows a question priority to determine its credibility [7], [99], [70], [38]. For example, let's say an assessment asks if the front door of the building is accessible versus the sound levels of the building environment. For a person with mobility difficulties, the weighting of the entrance will dwarf the importance of sound levels. If the individual cannot enter the building, the sound levels are moot.

4.7.2 Lack of comprehensive assessments

Lack of comprehensive assessments fail to work across all types of disabilities. For example, one of the significant challenges of accessibility measurement is whether it will work for individuals with physical, cognitive, or sensory disabilities. This challenge is often oversimplified. For example, even the category of sensory disabilities includes both visual and auditory disabilities, which are radically different from each other. Furthermore, the accessibility for people with vision impairments significantly differs between

				is short form	definition	choice 1	choice 2	choice 3	choice 4	choice 5	help text	standard	numerical
Health Safety Measures				y	Precautions are enforced by the restaur	2,""	1,"Begin"	0,""	,	,	Health Sa	See speci	N/A
	Protective Equipment			y	Protective equipment such as face mask	2,""	1,"Contin	0,""	,	,	Individual	No ADA-A	N/A
		Face masks			Disposable face masks that cover mouth	2,"Yes"	1,"Maybe	0,"No"	,	,	Patrons sh	No ADA-A	N/A
		Gloves			Disposable gloves are readily available f	2,"Yes"	1,"Maybe	0,"No"	,	,	Patrons sh	No ADA-A	N/A
	Hand Sanitization			y	Hand sanitization stations are available	2,""	1,"Contin	0,""	,	,	Hand sani	No ADA-A	N/A
		Visibility			Hand sanitizer dispenser is apparent.	2,"Yes"	1,"Maybe	0,"No"	,	,	There sho	No ADA-A	N/A
		Dispenser Access			Hand sanitizer dispenser is unobstructe	2," Yes"	1,"Maybe	0,"No"	,	,	The path t	No ADA-A	N/A
		Dispenser Height			Hand sanitizer dispenser is accessible wl	2," Yes"	1,"Maybe	0,"No"	,	,	The dispe	No ADA-A	N/A
		Dispenser Stability			Hand sanitizer dispenser is fastened in a	2," Yes"	1,"Maybe	0,"No"	,	,	The positi	No ADA-A	N/A
		Dispenser Usability			Hand sanitizer dispenser is easily operat	2," Yes"	1,"Maybe	0,"No"	,	,	The dispe	No ADA-A	N/A
		Signage			Signs are posted throughout restaurant	2," Yes"	1,"Maybe	0,"No"	,	,	The resta	No ADA-A	N/A
	Social Distancing			y	Features are spaced 6 feet apart.	2,""	1,"Contin	0,""	,	,	Features t	No ADA-A	N/A
		Seating Area			Easily able to sit 6 feet apart in seating a	2," Yes"	1,"Maybe	0,"No"	,	,	All seating	No ADA-A	N/A
		Wait Line Markers			Restaurant has wait line markers on the	2,""	1,"Contin	0,""	,	,	There are	No ADA-A	N/A
			Spacing		Designations are marked 6 feet apart on	2," Yes"	1,"Maybe	0,"No"	,	,	There is 6	No ADA-A	N/A
			Visible		Wait line markers are in clear view.	2," Yes"	1,"Maybe	0,"No"	,	,	The wait l	No ADA-A	N/A
			Contrast		Wait line markers have contrast separat	2," Yes"	1,"Maybe	0,"No"	,	,	The wait l	No ADA-A	N/A
	Policy			y	Restaurant has implemented safety poli	2,""	1,"Contin	0,""	,	,	Restauran	No ADA-A	N/A
		Patron Face Masks			Restaurant requires patrons to wear fac	2," Yes"	1,"Maybe	0,"No"	,	,	All restau	No ADA-A	N/A
		Employee Face Masks			Restaurant requires employees to wear	2," Yes"	1,"Maybe	0,"No"	,	,	All restau	No ADA-A	N/A
		Gloves			Disposable gloves are readily available f	2,""	1,"Contin	0,""	,	,	Building s	No ADA-A	N/A

Figure 4.1: Current taxonomy based on TTSS [1]
, [38]

Figure 4.2: iPad

a blind person and someone who is not blind but has low vision [4], [111], [113].

Figure 4.3: iPhone with red meter for sound data collection [2]

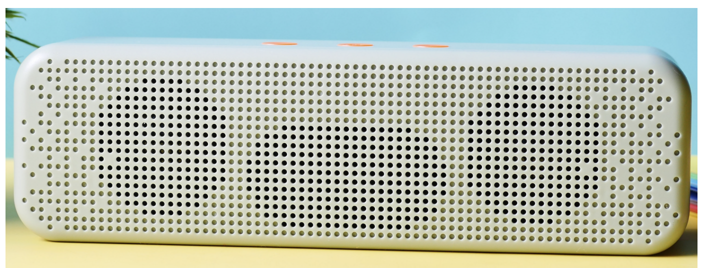


Figure 4.4: Bluetooth speaker

Figure 4.5: iPad with red meter for sound data collection [2], [3]

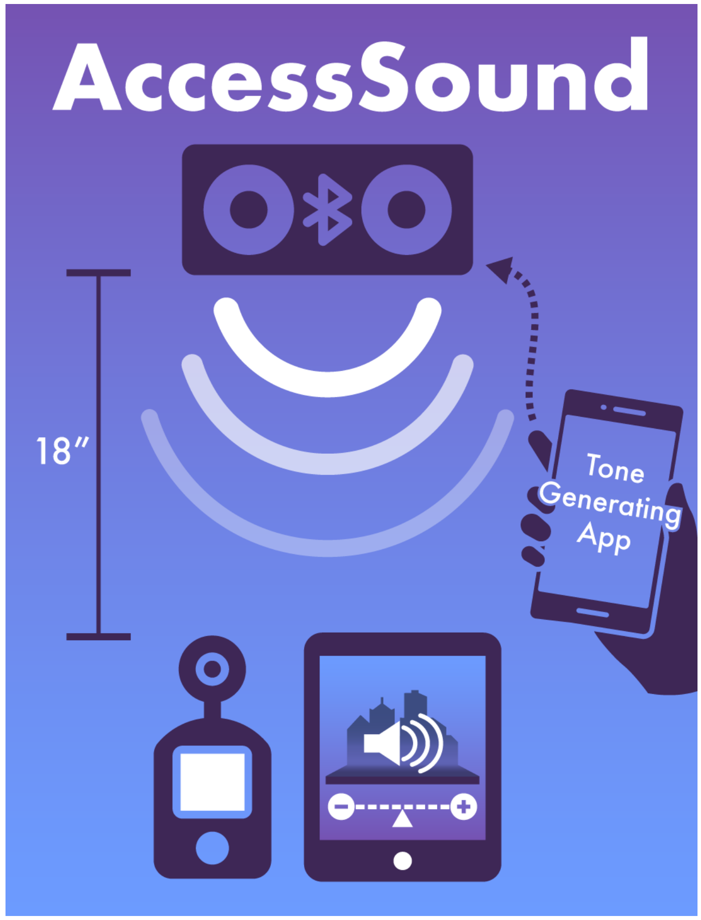


Figure 4.6: Accesssound data collecting protocol [2], [3]

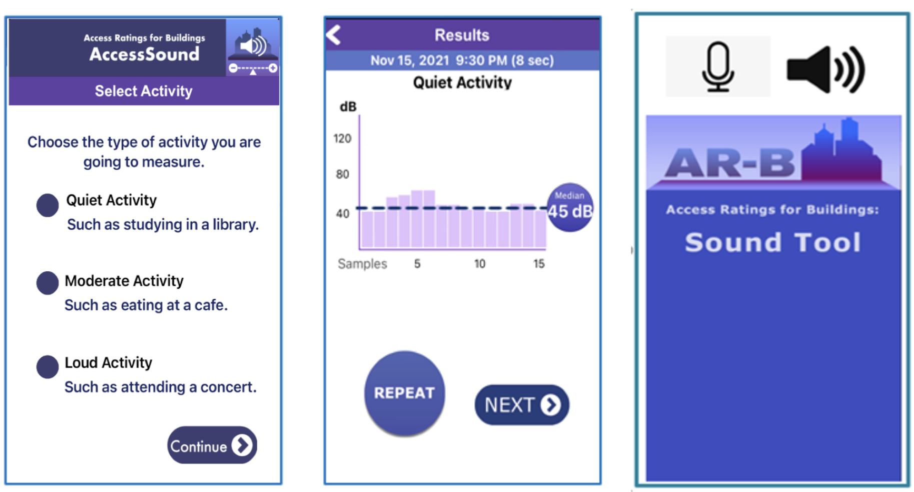


Figure 4.7: AccessSound application [1], [4], [2], [3]

4.7.3 Individual's combination of disabilities

Assessments ignore an individual's combination of disabilities. Measurement must work for a complex set of a person with a disability. For example, if someone has a vision impairment and a dexterity impairment, this could be a unique combination. Most assessments do not address combinations of disability impairments [4], [114].

4.7.4 Insufficient detailed

Accessibility outcomes assessments may not be sufficiently detailed. They may only have a few general questions. They may miss the detailed features of a building and the need for a specific accessibility design feature. Most assessments do not specify features such as whether a doorway is wide enough [4], [112].

4.7.5 Quantitative global summary

Assessment fails to produce a quantitative global summary of accessibility. The measurement may examine detailed building features but does not create a summary outcome statistic for which buildings can be compared. For example, an assessment may list specific remodeling or design needs but does not consolidate a score as an overall rating, such as this place is 70 percent accessible for blind people [4], [113].

Red Meter	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
50 Hz	39.5	39.3	40.1	39.5	39.5	39.6	40.7	40.7	40.1	40.7
100 Hz	39.7	39.7	40.1	42.7	45.7	49	53.3	55.2	61.6	64.1
200 Hz	44.2	49.7	51.8	56.8	60.1	65.6	71.2	74.1	80	82.9
400 Hz	55.1	60.9	63.4	67.8	71.5	76.8	82.3	84.9	90.5	93.2
800 Hz	63.7	69.3	71.9	77.6	80.8	86.5	92.7	95.4	100.2	102.3
1600 Hz	63.4	68.6	71.3	77.4	80.3	85.8	91.6	94.4	99.8	102.3
3200 Hz	63.4	70.1	73	79	80.4	87.9	94.6	97	102.7	105.4
6400 Hz	60.4	66.6	68.4	74.4	78	84.1	89.1	92.4	98.2	101.1
12,800 Hz	39.3	39.9	40.5	43.3	44.5	64.7	68.6	72.2	76.6	79.9
17,000 Hz	39.8	39.8	39.5	41.3	42.2	45.9	65.7	69.1	75.1	77.5
iPhone 12	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
50 Hz	33	34	32	36	31	28	29	31	31	33
100 Hz	31	29	31	30	28	24	18	16	12	10
200 Hz	31	32	27	24	20	15	11	9	5	4
400 Hz	27	23	20	16	13	9	6	7	7	8
800 Hz	32	27	31	25	21	17	12	11	9	11
1600 Hz	29	25	24	18	15	13	13	13	13	14
3200 Hz	32	27	25	20	17	15	14	14	15	15
6400 Hz	32	29	28	24	21	17	15	15	15	15
12,800 Hz	44	47	30	34	30	28	23	23	18	17
17,000 Hz	32	30	29	27	25	21	17	15	15	15
Difference of data between Red Meter and iPhone 12										
Device	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
50 Hz	6.5	5.3	8.1	3.5	8.5	11.6	11.7	9.7	9.1	7.7
100 Hz	8.7	10.7	9.1	12.7	17.7	25	35.3	39.2	49.6	54.1
200 Hz	13.2	17.7	24.8	32.8	40.1	50.6	60.2	65.1	75	78.9
400 Hz	28.1	42.3	43.4	51.8	58.5	67.8	76.3	77.9	83.5	85.2
800 Hz	31.7	43.6	40.9	52.6	59.8	69.5	80.7	84.4	87.2	91.3
1600 Hz	34.4	43.1	47.3	59.4	65.3	72.8	78.6	81.4	86.8	88.3
3200 Hz	31.4	39.6	48	59	65.4	72.9	80.6	83	83.2	90.4
6400 Hz	28.6	37.6	40.4	50.4	57	67.1	74.1	77.4	83.2	86.1
12,800 Hz	4.7	7.1	10.5	9.3	3.7	36.7	45.6	49.2	58.6	62.9
17,000 Hz	7.8	9.8	10.5	14.3	20.5	24.9	48.7	54.1	60.1	62.5

Red Meter	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
50 Hz	43.1	42.4	41.3	42.4	42.5	41.9	41.7	42	41.9	42.6
100 Hz	40.9	41.1	41.7	44.4	45.4	49.2	52.5	55.6	61.7	64.9
200 Hz	45.3	49.5	51.8	55.7	62.5	65.4	71	74.3	80.2	83.3
400 Hz	57.8	63.6	66.1	72.1	76	81	86.4	88.9	95	97.5
800 Hz	50.6	55.9	58.4	63.7	70.3	73.2	78.4	79.7	84.7	91.3
1600 Hz	62.9	68.9	71.2	77.4	80.7	86.3	91.4	93.8	99.5	101.7
3200 Hz	61.8	66.2	70.6	76.5	79.8	85.5	90.9	93.5	100.3	102
6400 Hz	51.6	65.1	67	73.4	77	82.6	87.8	90.6	95.9	99.2
12,800 Hz	42.8	44.6	45.8	48.7	68.8	71.3	78.1	78.5	84.4	89.4
17,000 Hz	40.7	41.1	40.8	41	43.5	48.8	60	63.5	69.7	70.6
iPhone 12	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
50 Hz	65	67	65	66	67	64	64	63	64	63
100 Hz	65	66	68	69	71	75	83	86	96	95
200 Hz	65	66	70	75	85	91	101	106	114	117
400 Hz	70	75	81	92	97	105	106	106	107	107
800 Hz	67	68	67	70	68	79	89	91	94	98
1600 Hz	71	77	81	92	93	93	94	94	95	94
3200 Hz	72	82	87	92	92	92	93	92	92	91
6400 Hz	66	68	70	76	82	89	90	90	89	90
12,800 Hz	65	67	65	69	75	81	89	90	92	92
17,000 Hz	63	65	66	64	64	64	65	65	65	65
Difference of data between Red Meter and iPhone 12										
Device	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
50 Hz	21.9	24.6	23.7	23.6	24.5	22.1	22.3	21	22.1	20.4
100 Hz	24.1	24.9	26.3	24.6	25.6	9.6	30.5	30.6	34.3	30.1
200 Hz	19.7	16.5	18.2	19.3	22.5	20	30	31.7	33.8	33.7
400 Hz	12.2	11.4	81	92	21	24	19.6	17.1	12	9.5
800 Hz	16.4	12.1	67	70	2.3	5.8	19.6	1.3	9.3	6.7
1600 Hz	8.1	8.1	81	92	12.3	6.7	2.6	0.2	4.5	7.7
3200 Hz	10.2	15.8	16.4	15.5	12.2	6.5	2.1	1.5	8.3	11
6400 Hz	14.4	23.4	3	2.6	5	6.4	2.2	0.6	6.6	9.2
12,800 Hz	22.2	22.4	19.2	20.3	3.7	9.7	0	11.5	7.6	2.6
17,000 Hz	22.3	23.9	25.2	23	20.5	15.2	5	1.5	4.7	5.6

Figure 4.8: Using ML algorithm the improvement of sound data [2], [3]

4.7.6 Not applicable for all building types

Assessments do not work for all building types. Measurement must account for all types of buildings. For example, a restaurant has unique features different than a university building or museum [4].

4.7.7 Quantitative and qualitative (personal experiences)

Integrating quantitative and qualitative data methodologies poses another significant challenge in accessibility measurement [4], [116]. Objective data, such as measurements of door widths, ramp incline, availability of handrails, and restroom accessibility, are crucial for assessing accessibility. Additionally, considering user subjective experiences, such as ratings and comments, is equally important. While qualitative data is often included in website assessments, empirical data is sometimes overlooked. Therefore, comprehensive and informative accessibility measurements should encompass both quantitative and qualitative data simultaneously to capture the complexity of information and provide a more holistic understanding of accessibility [116], [117], [118].

4.7.8 Lengthy and lack efficiency

Comprehensive assessments tend to be lengthy and lack efficiency. To be comprehensive in the many dimensions of questions described above, complete assessments are often complex and lengthy with many questions. These are impractical for the time and resources available by personnel to complete the assessments [4], [119].

4.7.9 Lack psychometric validation

Assessments often lack psychometric validation. Current assessments have insufficient documented reliability and validity for appropriate decision-making. For assessments to support evidenced based practice, key types of reliability and validity must be published [4], [2]. The above accessibility measurement challenges pose difficulties for PwD to fully participate in the community. A building accessibility evaluation and assessment must incorporate solutions to the proposed challenges to maximize PwD community participation and independence [4], [7].

4.8 How we can solve accessibility measurement challenges?

To address the accessibility measurement challenges of public buildings, several strategies can be employed.

4.8.1 Clear and Consistent Accessibility Standards

Establish clear and consistent accessibility standards and guidelines that apply to all public buildings. These standards should be updated regularly to reflect advancements in accessibility knowledge and technology. Ensuring consistency across jurisdictions helps evaluators have a standardized framework for assessing accessibility [4].

4.8.2 Enhanced Accessibility Training and Education

Provide comprehensive accessibility training and education for architects, designers, builders, and other professionals involved in public building design and construction. This includes raising awareness about accessibility requirements, best practices, and the importance of inclusive design. Continuing education programs can help professionals stay updated with evolving accessibility standards [4].

4.8.3 Improved Access to Information

Enhance access to accurate and comprehensive information about public buildings. Maintain centralized databases or repositories that contain relevant architectural plans, construction details, and accessibility features. This enables evaluators to access necessary information for accurate assessments and eliminates the need for redundant evaluations [4].

4.8.4 Collaboration and Stakeholder Involvement

Foster collaboration among evaluators, architects, building owners, disability advocacy groups, and government agencies. Engaging stakeholders in the accessibility measurement process allows for diverse perspectives and ensures that evaluations consider a wide range of accessibility needs [116], [118].

4.8.5 Enhanced Enforcement and Compliance

Strengthen enforcement mechanisms to ensure compliance with accessibility standards. Regular inspections, audits, and certification processes can help identify non-compliant buildings and encourage timely accessibility improvements. Providing resources and support to building owners and authorities can facilitate compliance efforts [4].

4.8.6 Technological Solutions

Technological solutions can play a significant role in tackling challenges related to measuring accessibility. Here are several ways in which technology can be instrumental: i) Automated Data Collection: Technology can automate the collection of objective accessibility data, such as measurements of doorways, ramps, and other physical features. This streamlines the process, ensuring data accuracy and consistency. ii) Digital Surveys and Feedback: Technology enables efficient collection of subjective data through digital surveys and feedback mechanisms. This empowers individuals with disabilities to share their experiences and provide valuable insights on accessibility. iii) Assistive Technologies for Data Collection: Assistive technologies like screen readers or voice input facilitate data collection from individuals with visual or physical impairments. This ensures that accessibility assessments are inclusive and representative of diverse user perspectives. iv) Augmented Reality and Virtual Reality: These technologies can create immersive simulations of buildings and spaces, enabling virtual accessibility assessments. By identifying potential barriers and evaluating design alternatives before physical construction, these solutions save time and resources. v) Data Visualization and Analytics: Technology aids in visualizing and analyzing accessibility data, making it easier to identify patterns, trends, and areas for improvement. Interactive dashboards and visual representations enhance the comprehension of complex accessibility information. vi) Mobile Applications: Mobile apps offer real-time navigation and accessibility information, assisting individuals with disabilities in navigating public buildings more effectively. These apps provide route guidance, highlight accessible features, and offer personalized assistance [120], [4].

By leveraging technological solutions, challenges in measuring accessibility can be addressed with greater efficiency and effectiveness. These solutions facilitate accurate data collection, enhance user engagement, enable inclusive assessments, and provide valuable insights for improving accessibility in public buildings [4], [113], [73].

4.8.7 User Engagement and Feedback

Involve individuals with disabilities and diverse user groups in the evaluation process. Solicit their input, experiences, and feedback to gain insights into the real-world accessibility challenges they face. Incorporate user perspectives to identify areas for improvement and prioritize accessibility features that have the most significant impact [4].

4.8.8 Public Awareness and Advocacy

Raise public awareness about the importance of accessibility in public buildings. Promote inclusivity, equality, and the rights of individuals with disabilities. Advocacy efforts can encourage community support and demand for accessible buildings, driving change and prioritizing accessibility in public spaces [121], [122]. By implementing these strategies, it is possible to overcome accessibility measurement challenges in public buildings and ensure that they are designed, constructed, and evaluated with accessibility in mind.

4.9 What is the difference between accessibility measurement and accessibility evaluation of a public building?

Accessibility measurement and accessibility evaluation of a public building are closely related but have distinct meanings and purposes:

As discussed in section 3.7, the accessibility measurement in the context of a public building involves quantifying or assessing the level of accessibility based on specific criteria, metrics, or standards. It focuses on objectively measuring the physical, sensory, or cognitive accessibility features and barriers in the building. This could include evaluating elements such as entrance accessibility, door widths, ramps, elevators, signage, and restroom facilities. Accessibility measurement provides a quantitative or qualitative understanding of the level of accessibility in the building, helping to identify areas that may need improvement [123], [124], [125]. The accessibility evaluation goes beyond measurement and involves a comprehensive assessment of the accessibility of a public building. It encompasses a broader scope, considering not only the physical features but also the building's usability, inclusiveness, and overall user experience. Accessibility evaluation involves gathering user input, conducting observations, and considering subjective factors to assess how well the building meets the needs of individuals with disabilities. It may involve analyzing factors such as wayfinding, lighting, acoustics, seating arrangements, communication accessibility, emergency evacuation procedures, and staff training [125], [126], [127].

In summary, accessibility measurement quantifies and assesses specific accessibility criteria in a public building. In contrast, accessibility evaluation takes a more comprehensive approach by considering user experiences, usability, and a broader range of factors. Accessibility evaluation provides a holistic view of the building's accessibility, identifying strengths and weaknesses to guide improvements and ensure a more inclusive and accommodating environment for individuals with disabilities [122].

4.10 what are the accessibility evaluation challenges of public building?

The accessibility evaluation of public buildings can present several challenges. Here are some common challenges that evaluators may encounter:

4.10.1 Complex and Diverse Building Types

Public buildings encompass various types of structures, including government offices, schools, hospitals, museums, and transportation hubs. Each building type possesses distinct design elements, functions, and accessibility needs. It is crucial for evaluators to have a comprehensive understanding of the specific accessibility guidelines and standards relevant to different building types. This knowledge ensures accurate assessments of their accessibility levels [127], [128], [129].

4.10.2 Lack of Consistent Standards

Establishing a consistent framework for evaluation can be challenging due to variations in accessibility standards and guidelines across jurisdictions or building codes. Evaluators face the task of navigating and interpreting these diverse standards to ensure compliance and effectively identify areas for improvement [130].

4.10.3 Evolving Accessibility Standards

Evaluators face the challenge of keeping pace with the periodic updates of accessibility standards and guidelines, which aim to incorporate advancements in knowledge and technology. Staying well-informed about the latest standards and understanding the implications of these updates can be demanding. It requires actively staying abreast of new regulations and ensuring that evaluations align with the most up-to-date accessibility requirements.

4.10.4 Limited Access to Information

Evaluators may face difficulties accessing complete and accurate information about the building's design, construction plans, and accessibility features. This lack of information can hinder the evaluation process and lead to incomplete or inaccurate assessments. Collaboration and communication with building owners, architects, and relevant authorities can help address this challenge.

4.10.5 User Experience Considerations

Accessibility evaluation should not solely focus on physical accessibility features but also consider the usability and user experience within the building. Assessing factors such as wayfinding, signage, lighting, acoustics, and communication accessibility requires a comprehensive understanding of how these elements impact individuals with disabilities. Evaluators may need to consult with accessibility experts, engage with user groups, or gather feedback from individuals with disabilities to evaluate user experience effectively [130], [128].

4.10.6 Time and Resource Constraints

Thorough accessibility evaluations of public buildings can be demanding in terms of time and resources, especially for larger or more complex structures. Evaluators may encounter limitations regarding available time, budget, and resources to conduct comprehensive assessments. To address these constraints, it is beneficial to prioritize areas with the highest impact and consider collaborating with other professionals. By focusing efforts on critical areas and leveraging collaboration, evaluators can ensure a comprehensive evaluation within the given limitations.

4.10.7 Ongoing Maintenance and Updates

Accessibility evaluation should be regarded as an ongoing endeavor rather than a one-time task. Public buildings undergo modifications, renovations, and changes over time, making it necessary to maintain accessibility and monitor compliance with evolving standards. Regular evaluations are essential to identify and address any accessibility barriers that may arise due to building alterations. This process requires collaboration with building owners to ensure continued accessibility.

Addressing these challenges, a combination of expertise, collaboration, ongoing education, and clear communication with stakeholders is crucial. By overcoming these challenges, accessibility evaluators can contribute to the creation of more inclusive and accessible public buildings, fostering environments that cater to the needs of all individuals [127], [128], [129].

4.11 How to solve accessibility evaluation challenges of public buildings?

To address the accessibility evaluation challenges of public buildings, consider the following strategies [127], [128], [129]:

4.11.1 Clear Accessibility Guidelines

Establish clear and comprehensive accessibility guidelines and standards for public buildings. These guidelines should cover various aspects such as entrances, pathways, signage, restrooms, parking, and communication accessibility. Having well-defined guidelines provides a consistent framework for evaluation and ensures that all aspects of accessibility are considered [4], [131].

4.11.2 Training and Education

Provide training and education programs for architects, designers, engineers, and other professionals involved in public building design and construction. This training should focus on accessibility requirements, universal design principles, and best practices for creating inclusive environments. Increasing the knowledge and awareness of professionals can lead to better-designed buildings that meet accessibility standards [130], [129].

4.11.3 Accessibility Experts

Employ or consult with accessibility experts who have specialized knowledge and experience in evaluating public buildings. These experts can provide guidance, conduct evaluations, and offer recommendations for improving accessibility. Their expertise can help overcome challenges and ensure accurate assessments [125], [124], [132].

4.11.4 Collaboration and Stakeholder Engagement

Foster collaboration among stakeholders involved in public building projects, including architects, building owners, accessibility advocates, and government agencies. Engage stakeholders in the evaluation process to gather diverse perspectives, share information, and ensure that all accessibility concerns are addressed [129].

4.11.5 Accessible Documentation and Information

Improve access to accurate and comprehensive documentation for public buildings. This includes architectural plans, construction details, and information about accessibility features. By making this information readily available, evaluators can have a better understanding of the building's design and identify potential barriers [30], [130], [127].

4.11.6 User Feedback and Input

Seek feedback from individuals with disabilities and diverse user groups who have experience navigating public buildings. Their insights and firsthand experiences can provide valuable information about the actual accessibility of the building. Engaging users in the evaluation process can help identify specific challenges and prioritize improvements.

4.11.7 Regular Audits and Inspections

Implement regular audits and inspections of public buildings to ensure ongoing compliance with accessibility standards. Conducting periodic evaluations can help identify barriers that may have arisen due to changes or modifications in the building. Regular inspections promote accountability and prompt action to address accessibility issues.

4.11.8 Public Awareness and Reporting

Raise public awareness about the importance of accessibility in public buildings. Encourage individuals to report accessibility barriers they encounter, whether through dedicated reporting systems or public feedback channels. Public awareness can generate momentum for change and drive the prioritization of accessibility in building design and evaluation [123], [123], [125].

4.11.9 Enforcement and Compliance

Strengthen enforcement mechanisms to ensure compliance with accessibility standards. This can involve regular monitoring, penalties for non-compliance, and a clear process for addressing accessibility complaints. Ensuring accountability for accessibility can lead to greater adherence to standards. These strategies can help overcome the challenges of accessibility evaluation in public buildings and foster the creation of inclusive environments that cater to the needs of all individuals. In response to these issues, our research has developed a solution with the goal of establishing a reliable, valid, and relevant assessment system for public buildings. We have created several prototypes to validate our concept, including five unique applications. These applications enable the collection of data from both individuals with disabilities and accessibility experts. They empower people to identify establishments that best meet their needs, plan alternative routes, arrange assistance, or avoid specific barriers [127], [132].

The project, named Access Rating for Buildings (ARB), comprises a set of user-friendly and portable evaluation and reporting tools. These tools allow building assessors to share detailed information about the accessibility of any building. The designed solution will be further elaborated at the end of this chapter.

4.12 How Artificial Intelligence can help to solve accessibility measurement and evaluation challenges of public building challenges?

4.12.1 Artificial Intelligence

Artificial Intelligence (AI) is the field of computer science that focuses on creating intelligent machines capable of performing tasks that typically require human intelligence. It involves developing computer systems that can learn, reason, solve problems, and make decisions. The goal of AI is to replicate human cognitive abilities, such as understanding natural language, recognizing images, processing data, and adapting to new situations [133], [119].

AI encompasses several subfields, including machine learning, natural language processing, computer vision, and robotics. Machine learning is a crucial aspect of AI, where algorithms enable computers to learn from large datasets and improve their performance without explicit programming. Natural language processing involves interpreting and generating human language, allowing computers to understand and communicate in a manner similar to humans [134], [135], [136]. Computer vision involves teaching machines to interpret and comprehend visual data, such as images and videos. Robotics focuses on creating physical machines that can interact with the physical world.

AI finds applications across diverse industries, including healthcare, finance, transportation, manufacturing, and entertainment. Examples of AI applications include virtual assistants, autonomous vehicles, image recognition systems, recommendation algorithms, and fraud detection systems [137], [138].

The AI models can contribute to solving accessibility measurement challenges in public buildings in several ways:

4.12.2 Automated Data Analysis

AI models can analyze large volumes of data related to public buildings, such as architectural plans, blueprints, images, and sensor data. They can automatically extract relevant information and identify accessibility features, potential barriers, and compliance with accessibility standards. This automated analysis can assist evaluators by providing quick and objective measurements [133], [138].

4.12.3 Image Recognition and Object Detection

AI models trained on image recognition and object detection can identify specific accessibility features in photographs or floor plans of public buildings. For example, they can detect wheelchair ramps, accessible parking spaces, or signage. This enables evaluators to assess the presence and quality of these features more efficiently [139], [140], [141], [142].

4.12.4 Natural Language Processing (NLP)

NLP techniques can be employed to analyze and extract information from textual documents, such as accessibility guidelines, building codes, or regulations. AI models can interpret and understand the requirements and recommendations for accessibility, aiding evaluators in understanding and applying the relevant standards [55], [56], [56].

4.12.5 Virtual Simulations and User Experience Testing

AI models can generate virtual simulations of public buildings, allowing evaluators to virtually navigate and experience the accessibility features. These simulations can simulate different user scenarios, such as wheelchair users or individuals with visual impairments, to identify potential accessibility issues and evaluate the effectiveness of existing features [137], [135].

4.12.6 Predictive Analytics for Accessibility Planning

AI models can utilize historical data on accessibility evaluations, user feedback, and building characteristics to make predictions about the accessibility of new or modified public buildings. This can help architects and designers anticipate potential accessibility challenges during the planning and design phase, facilitating proactive accessibility improvements [58], [59], [57].

4.12.7 Intelligent Assistants and Chatbots

AI-powered intelligent assistants or chatbots can provide information and guidance on accessibility features in public buildings. They can assist users in finding accessible entrances, accessible facilities, or navigating through complex buildings. These AI-powered assistants can be accessible through various platforms, such as websites or mobile applications.

[65]

4.12.8 Real-time Monitoring and Alerts

AI models can continuously monitor sensor data from public buildings to detect accessibility-related issues in real-time. For instance, they can identify crowded areas, detect malfunctioning elevators, or monitor environmental factors affecting accessibility, such as lighting or temperature. Real-time alerts can be generated to prompt timely intervention and maintenance [60], [61], . It is important to note that AI models should be developed and trained using diverse and representative data to ensure their accuracy and effectiveness. Human expertise and evaluation are still crucial in interpreting the results generated by AI models and making informed decisions regarding accessibility improvements in public buildings [7].

4.13 Some Popular Artificial Intelligence models for solving accessibility measurement and evaluation challenges

4.13.1 Decision Tree

The decision tree is a well-known machine learning model utilized in artificial intelligence for classification and regression tasks. It represents a graphical depiction of a sequence of decisions and their possible outcomes, intending to mimic human decision-making processes by learning from existing data [103], [20], [20], [143]. The fundamental structure of a decision tree encompasses nodes, branches, and leaves. Nodes correspond to decisions or tests based on specific features or attributes, while branches indicate potential outcomes or paths, and leaves represent the final decisions or predictions [144], [145], [146]. Followings are the steps how the decision tree model operates:

Data Preparation: The decision tree model necessitates labeled training data, where each instance is associated with a known outcome or class label. The data is preprocessed to ensure it is in a suitable format for analysis. i) Feature Selection: The model identifies the most informative features from the available dataset. It determines which features are most valuable for making predictions or decisions based on their capacity to divide the data into distinct classes or categories. ii) Building the Tree: The decision tree model employs an algorithm to iteratively split the data based on the selected features. At each node, the algorithm chooses the most suitable feature to divide the data into subsets that are as pure as possible in terms of the target class labels. This process continues until a stopping criterion is met, such as reaching a maximum depth or a minimum number of instances in a leaf node. iii) Making Predictions: Once the decision tree is constructed, it can be employed to make predictions or decisions for new, unseen instances. The model follows the branches and tests the features to classify or predict the outcome of the instance. It traverses the tree from the root node to a leaf node, where the final class label or value is determined. iv) Handling Uncertainty: Decision trees can accommodate uncertainty by incorporating probabilistic measures. Instead of assigning a single class label to a leaf node, the model can assign a probability distribution over the possible class labels based on the frequencies of different classes in the training data. v)Evaluation and Pruning: The decision tree model is evaluated based on its performance on a separate validation or test dataset. Pruning techniques may be applied to simplify the tree and prevent overfitting, which occurs when the model becomes excessively complex and performs well on the training data but inadequately on new data [144], [4], [2].

The decision tree model is widely recognized for its interpretability, as the decision rules can be easily comprehended and visualized. Nonetheless, it may suffer from overfitting if the tree becomes overly intricate and may struggle to generalize well to unseen data. To address these limitations, various variations and ensemble techniques, such as random forests and gradient boosting, have been developed to enhance decision tree performance [145], [73].

4.13.2 Random Forests

The Random Forests model is a widely used algorithm in artificial intelligence for classification and regression tasks. It belongs to the category of ensemble learning methods, which combine multiple decision trees to make predictions or decisions.

following are the steps how the Random Forests model operates:

i) Data Preparation: Like other machine learning models, the Random Forests model requires labeled training data, where each instance is associated with a known outcome or class label. The data is preprocessed to ensure it is in a suitable format for analysis [147]. Random Sampling: The Random Forests model employs random sampling with replacement, known as bootstrapping, to create different subsets of the training data for each decision tree in the ensemble. This helps introduce diversity and reduce the risk of overfitting [148]. ii) Feature Selection: For each decision tree, a random subset of features is chosen from the available dataset. This process ensures that different trees consider different sets of features, preventing any single feature from dominating the model's predictions. iii) Building Decision Trees: Each decision tree in the Random Forests model is constructed using a similar process to the basic decision tree model. The data is recursively split based on the selected features, aiming to create subsets that are as pure as possible with respect to the target class labels. However, unlike a single decision tree, the Random Forests model typically limits the tree's depth or the number of instances at each leaf to avoid overfitting [149]. iv)Prediction Aggregation: After all the decision trees are built, predictions are made for new, unseen instances. For classification tasks, each tree independently predicts the class label of the instance, and the final prediction is determined by majority voting. For regression tasks, the individual tree predictions are averaged to produce the final prediction. v)Evaluation and Tuning: The Random Forests model's performance is evaluated using validation or test data, employing various evaluation metrics such as accuracy, precision, recall, or mean squared error. If necessary, the model's hyperparameters, such as the number of trees, maximum depth, or the number of features considered at each split, can be adjusted to optimize performance. The Random Forests model is known for its robustness and ability to handle complex datasets. By combining multiple decision trees, it reduces the risk of overfitting and provides reliable predictions. It can effectively handle missing data and noisy features, making it suitable for a wide range of applications in finance, healthcare, image recognition, and other domains where accurate and interpretable predictions are crucial [150], [151], [148], [147], [149].

4.13.3 Linear Regression

Linear regression is an essential machine learning model employed in artificial intelligence for predictive analysis and regression tasks. It is a straightforward yet powerful algorithm that establishes a linear connection between input variables (features) and the target variable to facilitate predictions.

Here's a summary of how the linear regression model operates:

i) Data Preparation: The linear regression model necessitates a dataset comprising labeled training examples, where each instance contains input features and their corresponding target variable. The data is preprocessed to ensure it is in a suitable format for analysis.

ii) Feature Selection: The model identifies the most pertinent features from the dataset by assessing their correlation with the target variable. It determines which features exhibit the strongest linear relationship with the target variable and are most informative for making accurate predictions.

iii) Model Representation: In linear regression, the connection between input features and the target variable is represented by a linear equation of the form: y = w1x1 + w2x2 + ... + wn*xn + b Here, y represents the predicted target variable, x1, x2, ..., xn denote the input features, w1, w2, ..., wn indicate the corresponding weights or coefficients assigned to each feature, and b represents the bias or intercept term.

iv) Training the Model: The objective of training the linear regression model is to identify the optimal values for the weights (w1, w2, ..., wn) and the bias term (b) that minimize the discrepancy between the predicted values and the actual target values in the training data. This is typically achieved using optimization techniques such as gradient descent or normal equations.

v) Making Predictions: Once the model is trained, it can be leveraged to make predictions for new, unseen instances. The input features are multiplied by their respective weights, and the bias term is added to generate the predicted target variable.

vi) Evaluation: The performance of the linear regression model is assessed using metrics like mean squared error (MSE), root mean squared error (RMSE), or coefficient of determination (R-squared). These metrics gauge the accuracy and quality of the model's predictions.

Linear regression is widely adopted as it is an interpretable model capable of handling both single-variable and multiple-variable regression problems [152], [153], [92], [154], [155], [156], [157]. It assumes a linear relationship between input features and the target variable, making it suitable for scenarios where the relationship is reasonably linear. However, it may not perform well when the relationship is highly nonlinear or involves complex feature interactions. In such cases, more advanced regression models such as polynomial regression or nonlinear regression may be more suitable.

4.14 Methodology

To address challenges related to accessibility measurement and evaluation, this research proposes a solution called Access Ratings for Buildings (ARB). ARB is a comprehensive and portable evaluation and reporting tool that utilizes mobile applications integrated with machine learning algorithms to rate the accessibility of building features. The objective of ARB is to enhance the accuracy of accessibility measurement by establishing a reliable and trustworthy assessment system for public building accessibility [4], [2], [38], [6].

For individuals with disabilities (PwD), their families, friends, and building owners, ARB has developed multiple prototypes to validate the concept. The implementation of mobile applications provides up-to-date accessibility information on public structures. Through the ARB system, users can access both ADA information and user experience ratings conveniently on a single platform [38], [38], [73].

Additionally, ARB comprises five unique applications that quantify accessibility measurement information: AccessTools, AccessLight, AccessSound, AccessSlope, and AccessRuler. These applications facilitate the assessment of different accessibility aspects and contribute to a comprehensive evaluation of building accessibility.

Overall, the ARB solution aims to address accessibility challenges, provide accurate measurement and evaluation, and offer accessible information to users through innovative mobile applications.

4.14.1 Purpose of ARB

The purpose of ARB is to identify, document, and objectively measure the complete accessibility of different building elements. AccessTools and myAccessTools are unique, comprehensive, and efficient accessibility assessment tools that has been recently developed to be used by trained assessors. This tool aims to provide a comprehensive assessment of public buildings and objectively identify accessibility barriers hindering PWD from using these buildings. The primary goal is to design, develop, and deploy software applications that provide value and meet the requirements of users or organizations. The purpose of ARB summarized as follows:

i) Solve Problems: To address the challenges associated with accessibility measurement and evaluation, the Access Ratings for Buildings (ARB) system has been developed with the aim of improving the accuracy and reliability of accessibility assessments [19,20]. ARB provides a comprehensive solution for individuals with disabilities (PwD), their families, friends, and building owners by offering a range of prototypes and mobile applications that deliver real-time accessibility information for public structures. The following points outline how ARB effectively resolves accessibility measurement challenges: a) Solution 1: Deals with the importance (weighting) of questions from the question set asking - ARB follows a hierarchical approach in determining the importance of questions. It starts with essential aspects such as parking and front doors, progressing through a structured sequence. Matrices are employed in ARB, assigning weights to questions based on different disability types. These matrices encompass a list of disability types and associate weights with the questions. With a coverage of 16 impairment types, ARB ensures that questions are appropriately weighted for each specific disability.

To enhance user experience, ARB begins with users creating a personalized profile using system data. This profile enables the ARB application to display building information tailored to the individual's specific accessibility needs [4], [2], [7]. This personalized display offers a significant advantage by minimizing the time users spend sifting through irrelevant and unnecessary data. Users can choose to view building evaluation summaries or delve into details provided by other individuals with disabilities and building visitors who have shared personal accessibility testimonials and ratings for specific buildings provides an illustrative depiction of the taxonomy employed within the proposed ARB system. The personalized choice in ARB can be enhanced and made more efficient and reliable through the utilization of machine learning (ML) algorithms such as decision trees, random forests, linear regression, and other decision-making algorithms [4], [7], [6]. In this research, particular emphasis is placed on the analysis using decision trees. Decision trees are popular ML algorithms known for their simplicity and ability to streamline the decision-making process. They serve as a tool for identifying different options and their corresponding outcomes through predictive modeling [4].

The structure of a decision tree consists of a root node, which serves as the starting point, and leaf nodes, which represent the endpoints or decisions. In the proposed solution, the root node is based on user profile-specific data. For example, if the user intends to assess the accessibility of a restaurant, the root node in the decision tree would be "restaurant." The leaf nodes are the final outputs obtained through a series of decisions, represented by the end questions from the taxonomy [4], [2], [30].

The accuracy of the personalized question choice set, derived from the decision tree model, is reported to be 97 percent. This indicates the high precision and effectiveness of the decision tree algorithm in tailoring question selection to individual profiles.

The ARB system encompasses a comprehensive question set comprising more than 2600 questions, with plans for further expansion in the future. This solution aims to address all 16 different impairment types and covers various types of buildings and their respective features. However, a significant challenge within the question set lies in the presence of numerous similar and duplicate questions assigned to different building elements. For instance, questions regarding the accessibility measurement of bedrooms may exhibit considerable overlap with those pertaining to dining rooms, as the features involved are often similar. To mitigate this redundancy, the application of machine learning (ML) algorithms such as semantic text matching, long short-term memory networks (LSTM), and convolutional neural networks (CNN) can be employed. These algorithms effectively identify and remove duplications, enhancing the efficiency and accuracy of the accessibility measurement process. By employing these ML techniques, the aforementioned accessibility measurement challenges discussed in section II can be successfully addressed.

Solution 2: The proposed solution aims to be comprehensive, encompassing all disabilities and levels of disability. To address the presence of redundant data, including similar question sets and duplicate questions, an ensemble model is utilized in this study. Specifically, long short-term memory networks (LSTM) are employed to elimi-

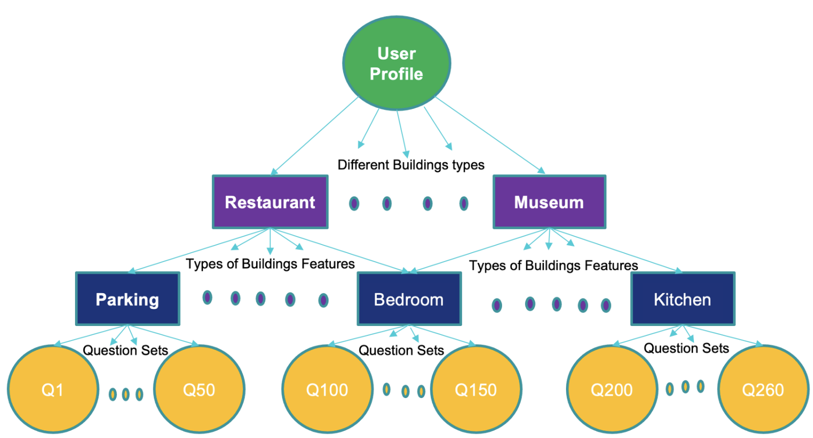


Figure 4.9: Choice of building evaluation based on Decision Tree

nate duplicate questions. LSTM is chosen based on previous studies that indicate its effectiveness in handling duplicity [158], [159], [160], [92], [161], [162], [163].

In addition, semantic text matching is implemented to address the issue of similar question sets. This model is currently in the implementation phase, and future results will be incorporated once testing is completed. By combining these approaches, the study tackles the challenges associated with accessibility measurements outlined in Section II, offering an effective solution for optimizing the evaluation process.

Solution 3: The ARB system efficiently caters to individuals with disabilities by offering an extensive question set that covers various building types, disabilities, and building features. To further enhance its efficiency, ARB utilizes a smart filtering approach to personalize the selection of choice-based questions. By tailoring the question set to the specific needs of each individual, ARB ensures an efficient and effective evaluation process. This aspect of ARB directly addresses challenge III, as outlined in Section II.

Solution 4: ARB employs a comprehensive question set for accessibility measurement, and then applies smart filtering using a decision tree based on personalized choice-based questions. This process ensures that the application effectively addresses the specific needs of individuals with disabilities. Consequently, ARB successfully resolves the fourth challenge related to accessibility measurement, as discussed in Section II. By identifying the specific features that require attention, ARB facilitates the identification of areas that need to be addressed and improved for enhanced accessibility [4].

Solution 5: After completing the rating of building features, ARB collects data and generates summary numbers to provide a global overview. For instance, when a user rates the main entrance, the app calculates an accessibility score between 0 and 100. Additionally, the assessment indicates whether the main entrance is accessible or not. For example, if the door is sufficiently wide and scores 80, it is considered accessible. This approach effectively tackles the fifth challenge pertaining to accessibility measurement, as discussed in Section II. By providing summary numbers and clearly indicating the accessibility status of each feature, ARB enables users to easily understand the overall accessibility of a building [2].

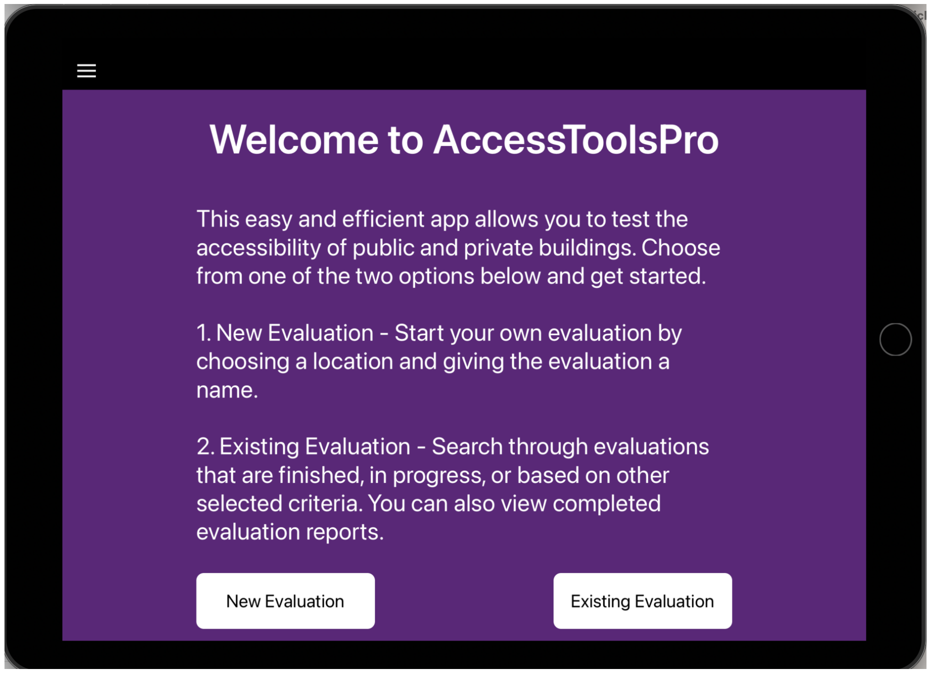


Figure 4.10: AccessTools UI - Welcome page [1], [4], [5], [6], [7]

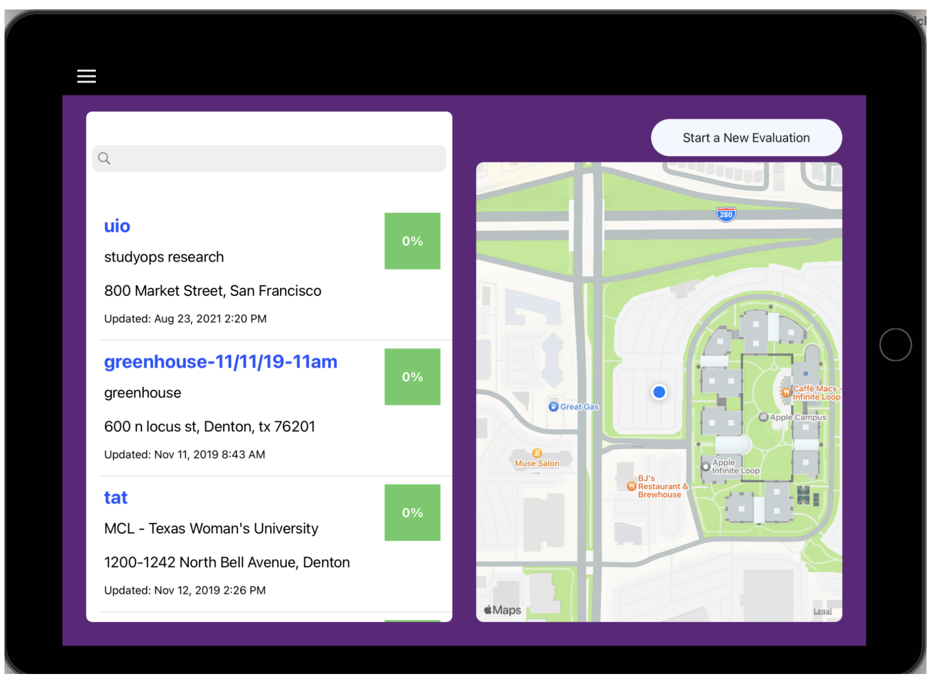


Figure 4.11: AccessTools UI - Existing Evaluation List [1], [4], [5], [6], [7]

Solutions 6 and 7: The ARB taxonomy encompasses a wide range of building types and their specific features. It is designed to be applicable to various types of buildings,

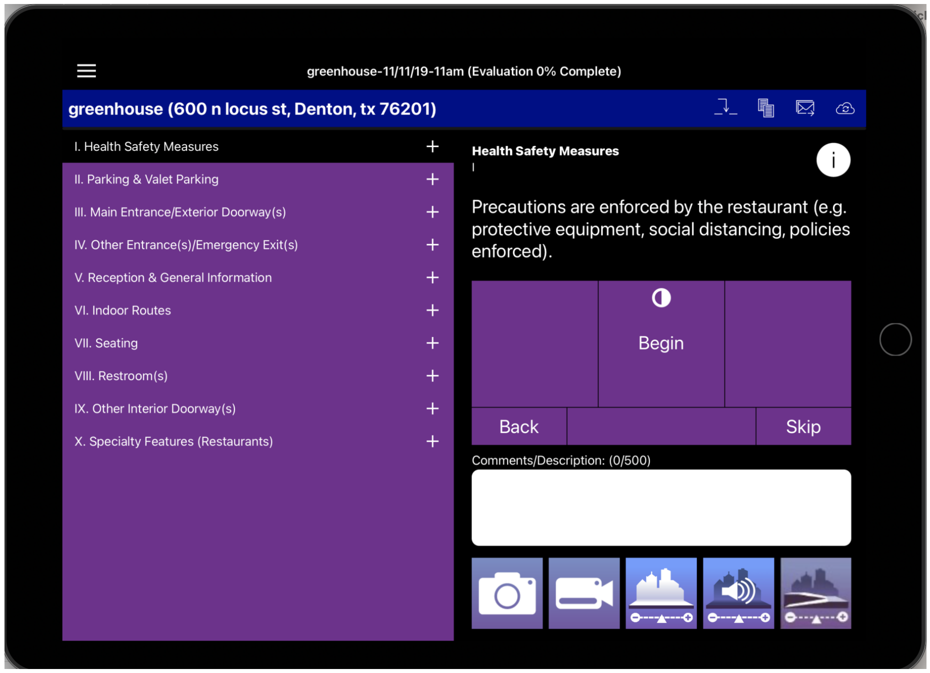


Figure 4.12: AccessTools UI - Question Branching [1], [4], [5], [6], [7]

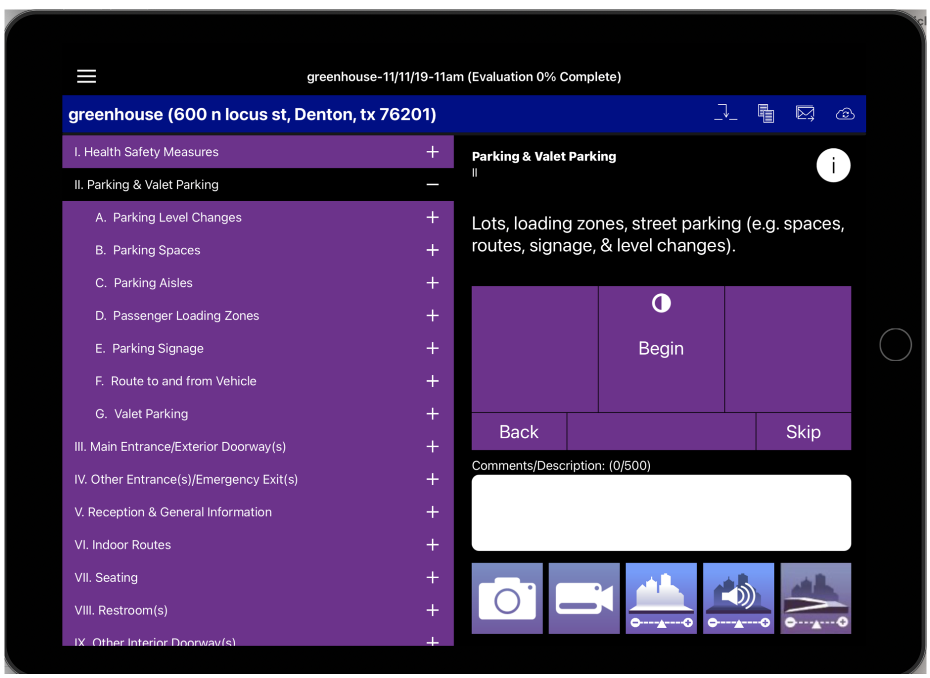


Figure 4.13: AccessTools UI - Question Subbranching [1], [4], [5], [6], [7]

taking into account the specific characteristics and features associated with each building type. The decision tree, as depicted is utilized to determine the appropriate building type based on user input and guide the assessment process accordingly. This ensures that ARB functions effectively for all types of buildings, while also considering the unique attributes and requirements of each specific building [4].

Solution 8: The ARB system captures both qualitative and quantitative aspects of building accessibility. Users can select the type of building, such as a restaurant or hospital, and choose relevant questions based on their selection. This approach allows for qualitative assessment, considering personal experiences and subjective factors. Additionally, ARB incorporates quantitative measurement by providing accessibility results displayed as percentages, reflecting the level of accessibility achieved through scoring algorithms. By offering a combination of qualitative and quantitative measurements, the ARB system effectively addresses the eighth challenge related to accessibility measurement [4].

Solution 9: To enhance measurement efficiency, ARB implements question branching using the Trichotomous Tailored Sub-Branching Scoring (TTSS) methodology. This approach enables users to gather detailed accessibility information specific to various building features. The question branching process for ARB is illustrated. If a user selects "Accessible" (score 2) or "Not Accessible" (score 0), the subsequent questions will skip the detailed question set and proceed to the next level. This streamlined process allows for efficient and faster accessibility measurement by focusing on key aspects [4], [2], [164], [148].

Conversely, if the user chooses "Somewhat Accessible" (score 1), all the detailed questions will be presented (sub-branching), providing a comprehensive evaluation to determine the true accessibility of a feature. This approach aids in identifying potential limitations and enables accurate data collection. By adapting the level of detail based on user responses, ARB promotes efficient and accurate assessment of accessibility features, optimizing the data collection process [4].

Solution 10: Reliability - One of the major challenges and issues of accessibility measurement is reliability on the accessibility measurement. ARB is reliable with the results it produces. In ARB, if the user chooses “Somewhat Accessible” 1, the question branches to follow-up questions that inquire more about the feature. This, along with the descriptions for each item, assists users with all types of accessibility knowledge and effectively scores items and rate-building features. Furthermore, data reliability is enhanced through the implementation of two machine-learning algorithm-based solutions [4].

Data reliability- Data reliability is a significant concern in the field of accessibility measurement [2]. To collect and assess accessibility data, users such as building assessors, owners, managers, and policymakers utilize their smartphones. These individuals rate various features of buildings, including parking, doorways, elevators, floors and ground surfaces, handrails, ramps, restaurants, restrooms, routes, seating, signage, and

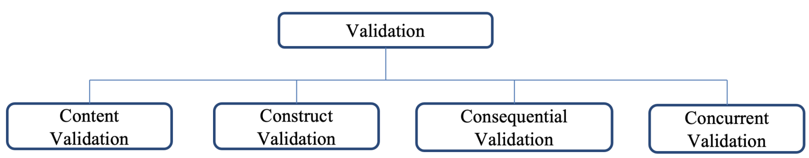


Figure 4.14: Types of validation

Accessibility Measurement Challenges for Buildings	Proposed Accessibility Measurement System for Building Access Rating for Building
Does the measurement deal with the importance (weighting) of questions from the question set asking about accessibility measurements?	Partially True
Does the measurement comprehensive across all disability and level of disability?	Yes
Is this works for individual's disability?	Yes
Does this measurement identify specific features that need to be fixed?	Yes
Does it provide global summary (numbers) of accessibility?	Yes
Does works for all types of buildings?	Yes
Does works for specific building?	Yes
Is it quantitative or qualitative (personal experiences)?	Both quantitative and qualitative
Is this measure efficiently?	Most efficient measurement system
Does this Reliability?	Yes, it is reliable
Is it a valid accessibility measurement system?	Yes

Figure 4.15: The list of result how ARB address the accessibility measurement challenges [4]

stairs [4]. Users record specific details pertaining to each area either while on-site or afterwards.

However, a critical issue impacting data reliability arises from the use of different devices. The variation in devices can lead to inconsistent results, compromising the reliability of the collected data. This issue of variability across devices presents a challenge that needs to be addressed to ensure the reliability and consistency of accessibility measurement data [2], [4], [90], [91], [165], [93], [166].

Different models of iPhones and Android phones exhibit variations in hardware components, including microphones, camera quality, and resolution. However, to address this issue, the research proposes multiple solutions. One of the proposed solutions involves leveraging machine learning (ML) algorithms to analyze the inconsistencies in hardware-related data and determine suitable resolutions.By applying ML algorithms, the research aims to identify patterns and correlations between the hardware variations and the resulting data discrepancies. This analysis can help establish a framework for adjusting and aligning the collected data to ensure greater consistency and reliability across different device models. This solution contributes to mitigating the impact of hardware-related variations on accessibility measurement, enabling more accurate and reliable data collection [2].

The initial challenge revolves around the inconsistency in sound data caused by variations in microphone configurations across different phone models. This disparity results in discrepancies between the collected sound data and the reference test data, leading to partially inaccurate evaluations of accessibility. To address this critical issue, the research implemented the pwlf package, which employs continuous piecewise linear functions specific to each device, ensuring precise evaluations and resolution of the problem [5], [73], [4], [2].The pwlf package utilizes two optimization techniques to determine the best piecewise model. The outer optimization, known as differential evolution, is employed to locate the breakpoints in the data series. These breakpoints are then used in the inner optimization process, called the least squares fit, to determine the most suitable continuous piecewise linear function. The research primarily focuses on sound data recorded from iPhones (while considering all possible phone models in future studies) and uses A-weighted decibels (dBA) as the output. A-weighting is specifically applied to instrument-measured sound levels to account for the ear's relative loudness perception, as it is less sensitive to low frequencies. Due to limitations in the phone's speaker and microphone sensitivity, the measurement for low and high frequencies is not possible. Therefore, the research utilizes a frequency range of 400 Hz to 6400 Hz to develop the algorithm. The model's output provides a threshold value for each microphone type, which is then applied to the sound data of iOS devices. This seamless integration of the solution is accomplished through the AccessSound application, ensuring accurate evaluations of accessibility through precise sound data analysis [2].

The AccessSound application acts as a valuable tool for measuring decibel levels (dB) in enclosed areas and provides accessibility information based on the recorded sound measurements. Its main purpose is to report sound measurements and offer access to audio levels. By utilizing this application, users can accurately measure sound levels in enclosed spaces, overcoming concerns related to hardware-related inaccuracies [4], [2]. This solution presents a significant advantage by reducing reliance on device-specific measurements and enhancing the reliability and accuracy of the evaluation process. The data collection process is depicted in Figure 4, showcasing how sound measurements are collected using the AccessSound application. Figure 5 illustrates the organization and structure of the collected data, ensuring efficient management and analysis. Furthermore, Figure 6 visually represents the data collection process in a laboratory setting, highlighting the validation of the solution through the AccessSound application [2].

Overall, the AccessSound application plays a pivotal role in providing reliable and accurate sound measurements for assessing accessibility, offering users a robust and efficient tool to evaluate sound levels in various enclosed spaces.

The second challenge revolves around the inconsistency in light data due to variations in camera configurations and quality among different mobile devices. These variations can result in differing accessibility evaluations for light data, such as assessing sufficient brightness, low light conditions, or excessive brightness, even when evaluating the same light source [4], [2], [6], [7]. To address these issues related to hardware-related data disparities, the research conducted data collection for all possible iPhone camera configurations, with a primary focus on iPhones while considering all types of mobile devices for future research. The collected iOS devices were grouped based on their camera configurations, specifically the front and back cameras. Predictive analytics techniques were subsequently applied to mitigate these challenges. Predictive analytics encompasses a range of statistical techniques employed in this research. The model utilized lab-collected light data as input and generated a threshold value as output. This threshold value was then applied to the collected iOS data from the lab. As a result, regardless of the camera configuration, consistent light-level data was obtained from all iOS devices. Figure 7 illustrates the light data collection process for two different models of iPads using the same light source. It is evident that the data differs between the two models based on the camera used, despite the identical light source. For this research, thirteen different models of iPads were initially considered. Two types of light meters, namely the orange light meter and black light meter, were utilized, with the average data serving as the standard. The threshold value was applied to the collected light data, resulting in consistent data across all device models. This research significantly enhances the reliability of accessibility evaluation data, reduces device dependency, and increases the accuracy of the resulting data. In initial testing, the model achieved an accuracy of 92 percent for iOS devices (iPhone, iPad). Figure 8 showcases the AccessLight application, which is integrated with the light algorithm. Together with the AccessSound application, AccessLight, and two other applications, namely AccessSlope and AccessRuler, it is integrated into the AccessTools application, which facilitates building accessibility evaluations. Through the integration of the AccessSound, AccessLight, and other relevant applications, this research offers an innovative approach to address the challenges associated with measuring light data and ensure reliable and accurate accessibility evaluations in building assessments [1], [8], [2], [4].

By leveraging machine learning algorithms, this research effectively tackles the limitations imposed by device hardware and sensors, paving the way for significant advancements in rehabilitation systems, particularly in the field of building accessibility measurement. Through the utilization of sensors available in iPhones and iPads, the proposed solution empowers users to efficiently assess slopes, sound levels in decibels, inclines, brightness, and distances. This eliminates the need for separate tools such as tape measures, levels, and clipboards. Additionally, these measuring applications offer the capability to capture photos and videos of specific building elements, providing a comprehensive representation of identified accessibility barriers. Future endeavors will prioritize the refinement of sound and light algorithms to further enhance their performance. While the current focus centers on analyzing hardware data from iOS devices for light and sound algorithms, forthcoming research will encompass the potential integration of various other types of devices. This inclusive approach aims to expand the applicability and impact of the proposed solution to a broader range of devices and accessibility evaluation scenarios [2], [4], [30].

Solution 11: Validity - Validation has lots of different kinds. The types of validations are- i) Content validation: Content adequacy measures how well a test covers all relevant parts of the construct it is designed to measure. For the building measurement, ARB covers all the parts of accessibility testing, for example, from parking to the front door to light intensity, and also the question set is validated by accessibility experts, so this solution meets content validation [107], [4], [2]. ii) Construct validation: Construct validity is how well a test measures the evaluated concept. It is important to establish the overall validity of the method. For example-does, does this measure the accessibility of a building? If "Yes," is the relevant questions there? Or it measures the accessibility of roads? ARB measures the accessibility of a building that it is designed for. So, this measurement passes the construct validity testing [40], [7]. iii) Consequential validation: The term "consequential validation" relates to whether a test has favorable or unfavorable societal repercussions. For instance, the consequence validity of standardized examinations includes several advantageous features, such as better student motivation and learning and assuring that all students have access to the same curriculum. Although it may conceivably be used in other domains, this form of validity almost often refers to something that contributes to society. So, the question is, does this scale help people with disabilities? ARB has the consequence of having the measure. Because if users use the ARB application AccessTools for rating a public building, for example, a classroom. That information will be helpful for students with some kind of physical or cognitive disability. The school management can also take necessary steps to make their classroom accessible for all students [4]. iv) Concurrent validity: The degree of agreement between two measurements or assessments made simultaneously is displayed by concurrent validity. It contrasts a brand-new test with one that has already undergone testing and been shown to be reliable. Here the question is, does ARB have all the required questions for measuring buildings accessibility, which is required by ADT measure accessibility buildings policy? Another question is whether ARB measurement accessibility and ADT measurement accessibility are the same. For the first question, ARB covers all questions of ADT for measuring building accessibility, and Arb is not the same as ADT. It is a more comprehensive, expert-based intelligent system for measuring building accessibility. So, ARB passes the concurrent validity [2], [4].

Through the conducted literature review, this study delves into numerous challenges and issues associated with measuring the accessibility of buildings. To address these challenges, the research proposes a range of solutions based on machine learning algorithms, with a particular emphasis on ensemble approaches. Prominent machine learning algorithms like semantic text matching, long short-term memory networks (LSTM), and convolutional neural networks (CNN) are employed to mitigate redundancy in textual questions. By incorporating intelligent system-based questions, the decision-making process for measuring building accessibility is enhanced, resulting in a significantly improved user experience. Furthermore, the proposed solution includes a comprehensive set of weighted questions that are tailored to address both individual and general accessibility concerns. This research also focuses on achieving accessibility measurements that encompass all types of buildings and cater to specific types of accessibility needs. The proposed accessibility measurement system solution is not only efficient and reliable but also validated. This validation is exemplified through the integration of five accessibility measurement mobile applications within the ARB framework. A concise summary of how the proposed solutions effectively tackle the challenges of accessibility measurement is provided in Table 1. The researchers have strong confidence in the efficiency and reliability of their proposed system solution.

4.14.2 Architecture of ARB

Provide Value: To cater to the needs of individuals with disabilities (PwD), their families, friends, and building owners, the ARB system is being developed as a mobile and web-based platform. This system offers real-time accessibility information regarding

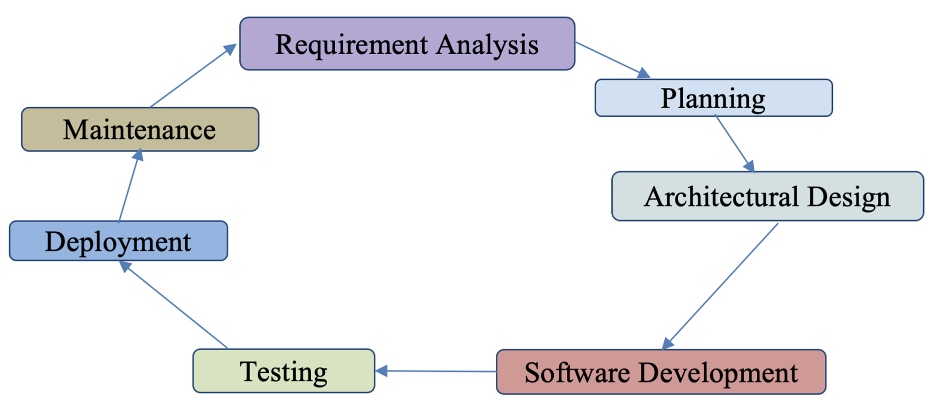


Figure 4.16: ARB software life cycle

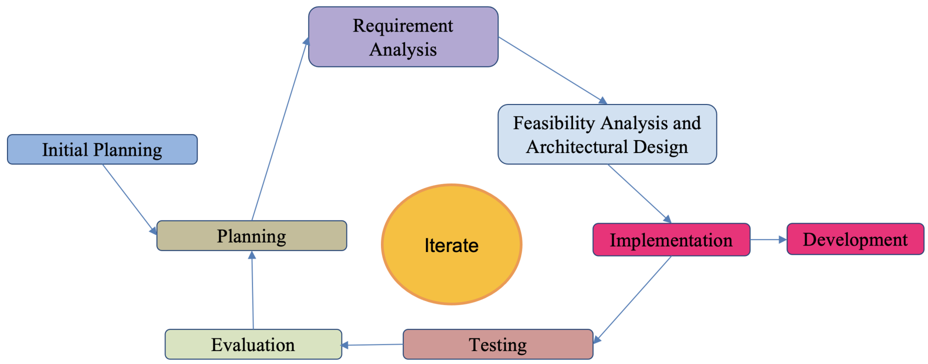


Figure 4.17: Iterative model followed by ARB

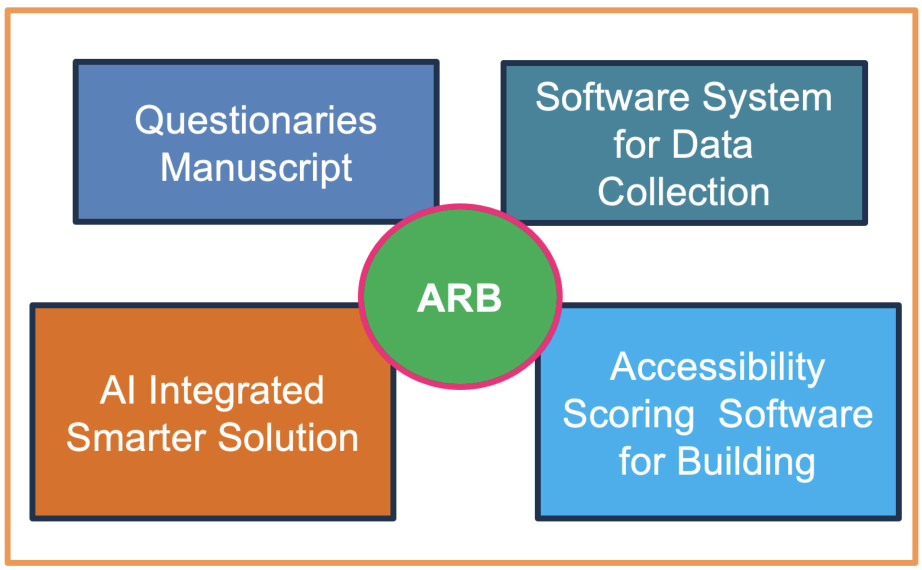


Figure 4.18: Different components of ARB

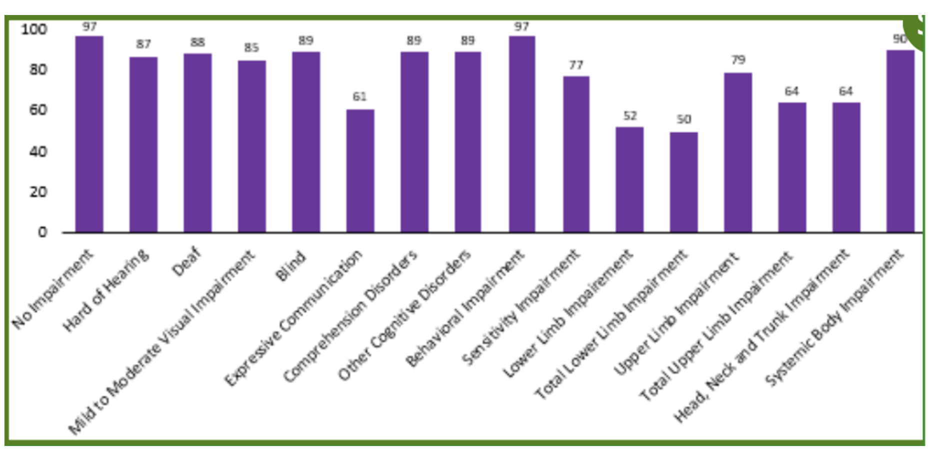


Figure 4.19: Scoring of main entrance of a building using myAccessTools

public buildings. Within the ARB system, users can access both ADA information and user experience ratings on a unified platform [4].The software bring several benefits, such as increased accuracy of existing measurement system , time and cost savings, improved decision-making and enhanced communication of PWD. The goal is to improve accessibility of public buildings.

Enable Innovation: ARB represents a pioneering advancement in data collection tools designed specifically for individuals with disabilities (PwD). It introduces a new dimension to the measurement of accessibility in public buildings. By leveraging ARB, there is a significant potential to enhance the accuracy of existing accessibility evaluations conducted for public buildings. This solution opens up new opportunities for improving the assessment and understanding of accessibility in these spaces [4], [2].

Enhance User Experiences: ARB boasts intuitive interfaces, smooth interactions, and seamless workflows, ensuring a user-friendly and enjoyable experience. The application incorporates all the accessibility features supported by iOS APIs, guaranteeing accessibility and inclusivity for all users. The developers of ARB have placed great emphasis on prioritizing user experiences, aiming to maximize user adoption and overall satisfaction

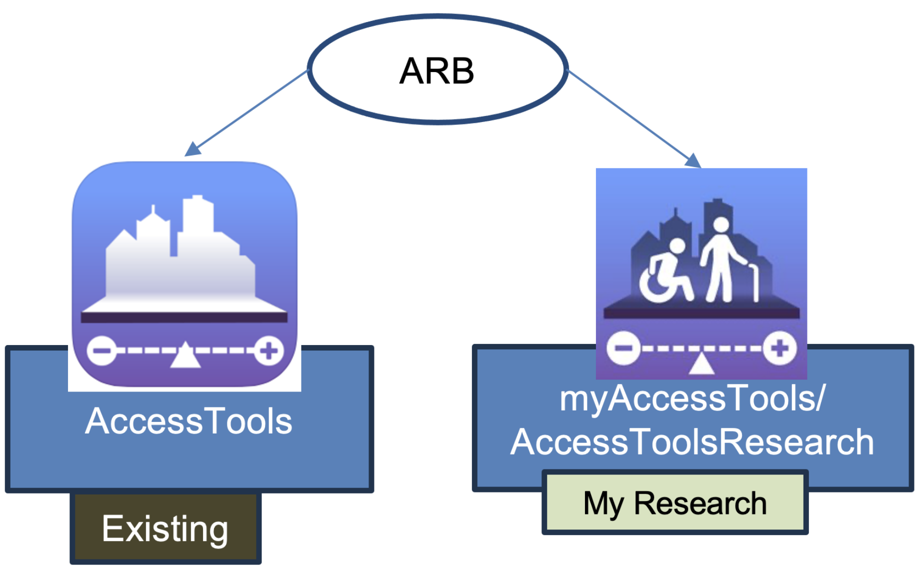


Figure 4.20: ARB existing works and the dissertation work contributions

with the application [4], [2].

Adapt and Evolve: The development of ARB adheres to iterative development processes, which promote flexibility and responsiveness to changes. The application undergoes rigorous reviews conducted by a dedicated testing team to ensure its quality and functionality. Additionally, a dedicated research team is responsible for planning future features and enhancements to continuously improve the existing app [4], [2].

Ensure Reliability and Quality: ARB is a highly reliable, high-quality, and robust application. Its primary goal is to create software that operates accurately, delivers excellent performance, and meets the desired standards. To achieve this, rigorous testing, thorough code reviews, and comprehensive quality assurance practices are implemented to guarantee the software's stability, security, and reliability [4], [2].

In summary, the development of the ARB application aims to create efficient and customizable software solutions to address existing challenges in accessibility measurement and evaluation. It seeks to provide value to people with disabilities, foster innovation, enhance user experiences, adapt to evolving needs, and ensure reliability and quality. By fulfilling these purposes, the development of ARB empowers individuals with disabilities and rehabilitation experts to leverage technology for improved accessibility and inclusivity [4].

4.14.3 Functionality

The first step for ARB users is to create a personalized profile, enabling the system to tailor the display of building information based on the individual's specific accessibility requirements. Users have the option to view summary reports or delve into the details, leveraging insights shared by other individuals with disabilities and building visitors who have provided personal accessibility testimonials and ratings for specific buildings. The assessment data on building accessibility is contributed by both visitors with accessibility needs and trained evaluators, ensuring a comprehensive evaluation of the public areas of the buildings [1], [66], [7].

The ARB incorporates a preliminary taxonomy [167], [167], [6]. This taxonomy encompasses various components such as user demographics, building types, general building elements, ADAAG requirements, additional functional accessibility elements, subjective experience rating domains, and individual subjective building element prioritization. These question sets are thoughtfully organized and structurally integrated to facilitate data collection and reporting interfaces. The ARB caters to three primary user groups: building users (including individuals with disabilities, friends, or relatives), building evaluators (encompassing advocates and building assessors), and building overseers (such as owners, managers, and policymakers).

This research endeavors to address significant challenges in the field, namely the development of an individual question set for assessment, reliable data collection, and accurate accessibility scoring. Currently, the process of filtering data from a vast question set is performed manually. However, this manual approach will be replaced by a decision tree, which is one of the most popular machine learning algorithms used for decision-making purposes [80], [168], [169], [170], [171]. The ARB system incorporates a preliminary taxonomy based on the Trichotomous Tailored Sub-Branching Scoring (TTSS) system [2]. TTSS is a powerful computer-based measurement scaling system used for observational self-ratings, known for its efficiency and methodological understanding. It quantifies responses using a trichotomous scale (0, 1, 2), where 0 signifies that no criteria are met, 2 indicates that all criteria are met, and 1 is assigned when some criteria are met or if the user is uncertain. The system also includes "not applicable" and "not examined" options as unscored responses to customize the assessment for each individual and their specific contexts [167], [52], [6].

The TTSS-based assessment tailors the evaluation to meet the individual's unique needs and contexts, as it includes items specific to the individual. The sub-branching feature allows for detailed analysis by leading users to more items, providing additional accessibility information, and optimizing efficiency. It also enhances reliability by enabling users to focus on specific details when necessary. In TTSS, only the endpoint questions are tallied, producing quantified scales for comparison between administrations [6], [52], [167], [172], [11], [168].

The taxonomy covers general building elements with accompanying descriptions that explain what to examine for each item. It incorporates a Help Text feature to assist individuals in accurately answering taxonomy items. Additionally, the taxonomy includes numeric requirements from the Americans with Disabilities Act Accessibility Guidelines (ADAAG) and a subjective experience rating domain, as well as individual subjective building element prioritization. These question sets are organized and integrated to create interfaces for data collection and reporting [168], [169], [172], [11], [171].

The ARB system serves three main user groups: building users (people with disabilities, friends, or relatives), building evaluators (advocates and assessors), and building overseers (owners, managers, policymakers). Users can personalize their profiles, enabling the system to display building information tailored to their specific accessibility needs. They can access summary reports or explore detailed information provided by other individuals with disabilities and building visitors who have shared personal accessibility testimonials and ratings for specific buildings.

Building accessibility evaluation data is populated by visitors with accessibility needs and trained accessibility evaluators. Trained evaluators comprehensively assess the public areas of buildings, collecting objective measurements and providing a comprehensive evaluation. The proposed ARB system, with its five different measurement applications, effectively addresses various accessibility measurement challenges outlined in section 2, employing machine learning algorithms to optimize efficiency [6].

4.14.4 Integration and Dependencies

ARB use some thirdparty libraries (chart master, etc.), and iOS APIs for server communication, data sync, data save on local device. ARB use AWS server, which is secure and user password protected [6].

4.14.5 Performance and Scalability

The ARB application demonstrates exceptional performance and scalability. It efficiently manages data by seamlessly transitioning between offline and online modes. Users need not worry about saving their data offline as it is automatically handled, eliminating the risk of data loss. In the absence of network connectivity, the data is securely stored locally and synchronized automatically once the connection is restored. Furthermore, the ARB taxonomy is dynamic, allowing the application to maintain consistent performance even as the dataset expands. This scalability feature ensures that the application performs reliably regardless of the size of the data, offering users a seamless and efficient experience [2].

4.14.6 Security

The ARB application prioritizes security and ensures the protection of user data. User data is safeguarded through user passwords, providing an additional layer of security. The server data is meticulously maintained by the trusted R2D2 research team, minimizing the risk of unauthorized access, data breaches, or any other security concerns. The ARB system is designed to uphold stringent security measures, ensuring the confidentiality and integrity of user information throughout the application's usage [4].

4.14.7 Deployment and Maintenance

This application is designed specifically for the iOS platform, ensuring compatibility with devices such as iPhones and iPads. The deployment of the solution is focused on iOS devices, guaranteeing a streamlined user experience. The application follows a systematic version release process using TestFlight, enabling controlled and iterative updates. To ensure effective maintenance and quality assurance, dedicated teams are assigned to testing and development tasks. Furthermore, there is a separate team responsible for managing the backend infrastructure and facilitating seamless communication with the server. This collaborative approach ensures the efficient operation and ongoing enhancement of the application [1], [4].

4.14.8 Explainable AI

Explainable AI, also known as XAI, refers to the capacity of artificial intelligence systems to offer understandable and interpretable explanations for their decisions and actions. While traditional machine learning models like deep neural networks often operate as "black boxes," generating accurate results without clear insights into their decision-making process, Explainable AI seeks to address this limitation. By providing insights into the reasoning behind AI predictions, it aims to make the decision-making process more transparent and comprehensible to humans.

Explainable AI plays a pivotal role in generating smart reporting through various means:

Enhanced Trust and Adoption: When AI-generated insights are accompanied by clear and coherent explanations, people are more likely to trust and embrace AI technologies. This holds particular significance in critical domains such as healthcare, finance, and autonomous vehicles, where AI decisions carry significant consequences. Identification of Biases and Errors: Explanations enable users to better comprehend any underlying biases or potential errors within AI models. This empowers them to identify and rectify issues, leading to fairer and more accurate reporting. Understanding Complex Models: Modern AI models are often highly complex and challenging to interpret. Explainable AI techniques help break down these models' behavior, facilitating stakeholders' understanding of the factors driving the AI's conclusions [173], [174], [175]. Compliance and Regulations: In regulated industries like finance and healthcare, explainable AI is indispensable for complying with laws and regulations. Smart reporting backed by clear explanations provides auditors and regulators with the necessary insights into the decision-making process. User Interaction and Collaboration: Explainable AI enables meaningful interaction between users and AI systems. Users can seek clarifications, provide feedback, and collaborate with AI tools to refine and improve the reporting process. Learning from AI Insights: By understanding how AI arrives at its conclusions, humans can learn from the AI-generated insights and use that knowledge to enhance their decision-making processes [176], [86], [177]. Adapting to Changing Data: Smart reporting generated by explainable AI can adapt to new data and changes in the environment more effectively. Users can assess the relevance and reliability of AI recommendations in dynamic scenarios. Explainable AI empowers users to make informed decisions, facilitates the integration of AI into various industries, and enhances the overall value and trustworthiness of AI-generated smart reporting [173], [174], [176], [175].

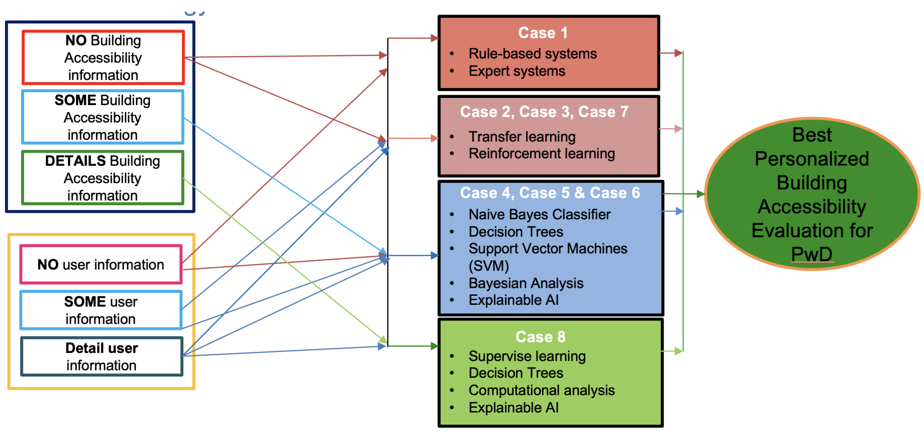


Figure 4.21: AI model based solution

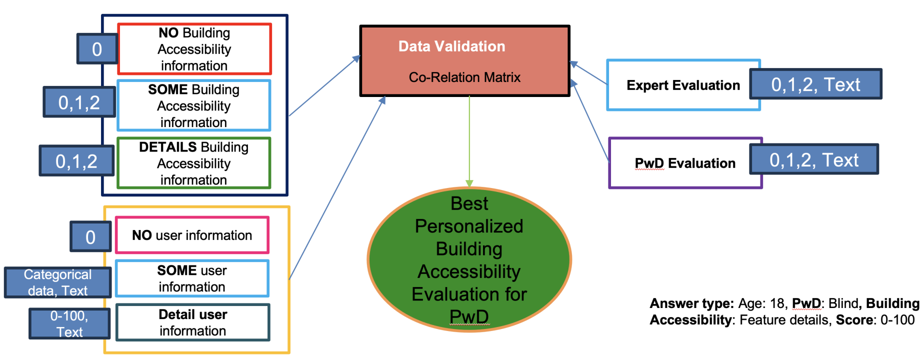


Figure 4.22: ARB software life cycle

4.14.9 User Interface

4.14.10 Architecture

Case 1: No building accessibility information (NO ARB App) + No user information (NO Access-Place or User Profile or Scoring)

Case 2: No building accessibility information (NO ARB App) + some user information (Scoring) or Access-Place + detail user information (Access-Place) and Scoring

Case 3:Some building accessibility information (ARB short form App) + NO user information (No Access-Place/ Scoring)

Case 4: Some building accessibility information (ARB short form App) + some user information (Access-Place) or Scoring

Case 5: Some building accessibility information (ARB short form App) + some user information (Access-Place) or Scoring

Case 6: Some building accessibility information (ARB short form App) + Details user information (Access-Place) and Scoring

Case 7: Details building accessibility information (ARB- LONG form) + No user information (No Access-Place or Scoring)

Case 8: Details building accessibility information (ARB- LONG form) + Some user information (Access-Place or Scoring) or Details user information (Access-Place) and Scoring

In summary, this study presents a robust, efficient, and valid accessibility measure-

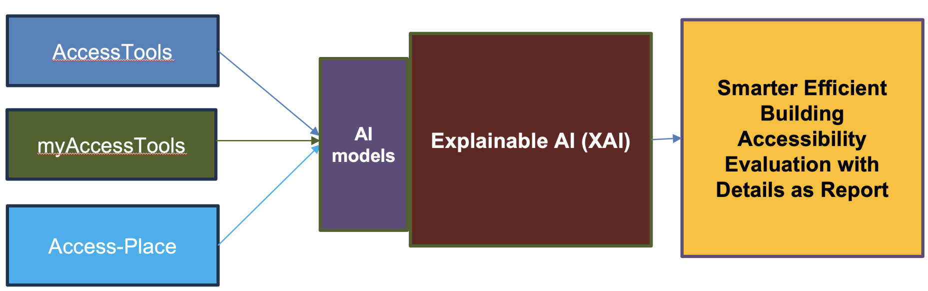


Figure 4.23: AI based solution

ment system solution utilizing mobile applications. By leveraging AI algorithm-based intelligent systems, the overall accessibility measurement system for buildings is significantly improved, offering benefits to the broader community and promoting independence for PwD. The proposed solution ensures increased consistency across mobile devices, enabling accurate interpretation and measurement of the built environment. The ultimate goal of this research is to enhance the engagement of PwD with the community by augmenting the accessibility of public buildings. The proposed system solution is verified in a specific group of people and the system solution is works only on iOS platform (iPhone, iPad).

Chapter 5
To Evaluate Home Accessibility using a Machine Learning based Intelligent System

5.1 Accessibility of a Home

The accessibility of a home refers to its design and features that allow individuals with disabilities or mobility limitations to live comfortably and independently. An accessible home eliminates barriers and provides accommodations to ensure that people of all abilities can navigate, use, and enjoy their living space. Here are some key considerations for home accessibility [178], [179], [180], [181], [182] .

Entrance: The home should have an accessible entrance, which may include features like ramps or zero-step entrances, wide doorways to accommodate mobility devices, and appropriate lighting [183].

Doorways and Hallways: Doorways and hallways should be wide enough to allow easy passage for individuals using wheelchairs or walkers. The recommended width is generally at least 32 inches for doorways and 36 inches for hallways [184].

Flooring and Surfaces: The home should have slip-resistant flooring to prevent falls, especially in areas prone to moisture like bathrooms and kitchens. Smooth and even surfaces are important for easy maneuverability.

Bathrooms: Bathrooms should be designed with accessibility in mind, including features like roll-in showers or walk-in tubs, grab bars, adjustable showerheads, raised toilets, and adequate space for maneuverability.

Kitchen: The kitchen should have counters and sinks at accessible heights, with knee space beneath the sink for individuals using wheelchairs. Lowered countertops or adjustable work surfaces can provide greater accessibility.

Lighting: Adequate lighting throughout the home is crucial for individuals with visual impairments. Bright and evenly distributed lighting, with switches placed at accessible heights, can enhance visibility and safety.

Staircases and Ramps: If there are multiple levels in the home, staircases should have handrails on both sides, consistent tread height, and contrasting nosings. Alternatively, ramps can be installed to provide accessible movement between levels.

Bedroom and Living Spaces: The layout of bedrooms and living spaces should allow for easy navigation and provide adequate space for maneuverability. This may involve ensuring clear pathways and appropriate furniture placement. Electrical and Environmental Controls: Accessibility can be improved by installing accessible switches, outlets, and controls at accessible heights. Lever-style door handles and faucets can also be easier to operate for individuals with limited dexterity.

Emergency Preparedness: Home accessibility should include provisions for emergency situations, such as accessible exits, clear signage, and alerting systems that accommodate individuals with hearing or visual impairments.

These are just a few examples of home accessibility considerations. The specific features required will depend on the needs of the individuals living in the home. Consulting with accessibility professionals, architects, or occupational therapists can provide valuable insights and guidance for creating an accessible home environment.

5.2 What is subjective and objective accessibility of home?

Subjective and objective accessibility of a private home follow the same principles as described earlier, but in the context of a residential setting. Let's define subjective and objective accessibility of a private home.

5.2.1 Objective Accessibility (Private Home)

Objective accessibility of a private home refers to the physical and measurable aspects of the home's design and features that facilitate access for individuals with disabilities. It involves meeting specific accessibility standards, guidelines, and building codes. Objective accessibility considerations in a private home may include features such as accessible entrances, door widths, accessible pathways, grab bars, ramps, accessible bathrooms, and other physical elements that ensure compliance with accessibility requirements. Evaluating objective accessibility involves assessing the home based on established criteria to determine if it meets the minimum standards for accessibility [48], [96], [95].

5.2.2 Subjective Accessibility (Private Home)

Subjective accessibility of a private home considers the personal experiences, preferences, and comfort of individuals with disabilities when living in and using the home. It takes into account the individual's unique needs, daily activities, and overall satisfaction with the accessibility features of their living environment. Subjective accessibility involves assessing factors such as ease of use, convenience, adaptability, usability of the home's layout and features, and overall satisfaction with the accessibility accommodations provided. This perspective acknowledges that accessibility is not solely determined by meeting objective criteria but also by ensuring that the home provides a comfortable and inclusive living environment tailored to the specific needs of the residents [94], [90], [18].

In summary, objective accessibility of a private home focuses on meeting physical accessibility standards and guidelines, while subjective accessibility considers the personal experiences and satisfaction of individuals with disabilities in their day-to-day living. Both perspectives are crucial in evaluating and improving the accessibility of private homes, ensuring compliance with regulations and creating an accessible and inclusive living space for all residents.

5.3 Why accessibility measure of a private home is important ?

The accessibility measure of a private home is important for several reasons:

5.3.1 Independent Living

Accessibility measures in a private home enable individuals with disabilities or mobility limitations to live independently and comfortably. By incorporating accessibility features, such as ramps, widened doorways, and accessible bathrooms, individuals can navigate their homes with ease and perform daily activities without relying heavily on assistance [18].

5.3.2 Quality of Life

An accessible home greatly enhances the quality of life for individuals with disabilities and their families. It promotes inclusion, freedom of movement, and a sense of empowerment. Accessible homes allow individuals to fully participate in family life, engage in hobbies, and maintain a sense of autonomy and dignity [185].

5.3.3 Aging in Place

As individuals age, their mobility and physical abilities may change. An accessible home allows older adults to age in place, meaning they can continue living independently and comfortably in their own homes rather than moving to assisted living facilities. Accessibility features, such as grab bars, non-slip flooring, and step-free entrances, can help prevent accidents and support aging in place [18], [185], [15].

5.3.4 Health and Well-being

An accessible home can contribute to the physical and mental well-being of its occupants. It reduces the risk of accidents and injuries, promotes ease of movement, and eliminates barriers that may cause stress or frustration. An accessible home can also accommodate the specific needs of individuals with medical equipment or assistive devices, facilitating their care and treatment [17], [18], [186].

5.3.5 Inclusive Environment

Creating an accessible home promotes inclusivity within the family and among visitors. It ensures that all family members and guests, regardless of their abilities, can comfortably and freely navigate and enjoy the home environment. An inclusive home fosters a sense of belonging and supports positive relationships among family members [178], [187].

5.3.6 Future-Proofing

Incorporating accessibility measures in a private home can be seen as future-proofing. It prepares the home for potential changes in the occupants' needs, such as if someone acquires a disability or develops mobility limitations over time. By considering accessibility during the design or modification of a home, it can be made adaptable and easily modified to accommodate changing circumstances [188], [189].

In summary, the accessibility measure of a private home is crucial for promoting independent living, improving quality of life, enabling aging in place, supporting health and well-being, fostering inclusivity, and future-proofing the home. It allows individuals with disabilities or mobility limitations to live with autonomy, dignity, and comfort within their own living environment.

5.4 Accessibility measurement challenges of private homes

When it comes to measuring accessibility in private homes, there are several challenges that can arise. Here are some common challenges:

5.4.1 Diverse Needs and Preferences

Private homes cater to the unique needs and preferences of individual homeowners or occupants. Each person may have different accessibility requirements based on their disabilities, mobility limitations, or personal circumstances. Designing and measuring accessibility in private homes must consider this diversity and provide customized solutions [187] [9].

5.4.2 Limited Regulatory Requirements

Unlike public buildings that are subject to specific accessibility laws and regulations, private homes often have fewer legal requirements regarding accessibility. This can result in inconsistent implementation of accessibility features, as homeowners may not be aware of or prioritize accessibility unless it directly impacts their own needs or the needs of their family members [190].

5.4.3 Cost and Affordability

Implementing accessibility measures in private homes can be financially challenging. Retrofitting or modifying existing homes to meet accessibility standards can involve significant costs. Homeowners may face financial constraints or lack access to funding or assistance programs, making it difficult to afford necessary accessibility modifications [191].

5.4.4 Age and Existing Infrastructure

Many private homes are older or have architectural features that may not easily accommodate accessibility modifications. Retrofitting such homes to incorporate accessibility features can be complex and costly. Structural limitations, narrow doorways, or multilevel designs can pose challenges to achieving comprehensive accessibility [9].

5.4.5 Lack of Professional Guidance

Accessibility expertise may not always be readily available or accessible to homeowners. Without proper guidance from architects, designers, or accessibility professionals, homeowners may find it challenging to navigate the process of assessing, planning, and implementing accessibility modifications in their homes. This lack of guidance can hinder the successful measurement and implementation of accessibility [9].

5.4.6 Personalization and Aesthetics

Homeowners often want to ensure that accessibility modifications align with the overall design and aesthetics of their homes. Finding the right balance between accessibility and maintaining the desired look and feel of the living space can be a challenge. It requires creative solutions and an understanding of accessible design principles to integrate modifications seamlessly [190].

5.4.7 Limited Awareness and Education

Many homeowners may lack awareness of accessible design principles and the benefits of incorporating accessibility features in their homes. Limited education and awareness campaigns can make it difficult for homeowners to understand the value and importance of accessible homes, resulting in a lower demand for accessibility improvements [191].

Overcoming these challenges requires a combination of education, awareness, financial support, and access to professional guidance. Providing resources, financial incentives, and promoting the benefits of accessible design can encourage homeowners to consider and implement accessibility measures in their private homes. Collaborative efforts between accessibility professionals, designers, policymakers, and advocacy groups can help address these challenges and promote accessible living environments for all individuals.

5.5 How we can solve accessibility measurement challenges of private home?

To address the accessibility measurement challenges of private homes, here are some potential solutions

5.5.1 Education and Awareness

Increase awareness among homeowners about the importance of accessibility in homes. Provide educational resources, guidelines, and best practices for incorporating accessibility features. Promote the benefits of accessible design, such as improved usability, safety, and future-proofing [192].

5.5.2 Accessibility Consultations

Offer accessibility consultations or assessments for homeowners. Provide access to professionals who can evaluate the home's accessibility and provide tailored recommendations based on the occupants' specific needs and preferences [193].

5.5.3 Financial Assistance and Incentives

Establish financial assistance programs or incentives to support homeowners in making accessibility modifications. This can include grants, tax credits, or low-interest loans to alleviate the financial burden associated with accessibility improvements [193], [194].

5.5.4 Accessible Design Guidelines

Develop and promote accessible design guidelines specifically tailored for private homes. These guidelines can provide homeowners with practical recommendations for incorporating accessibility features during construction or retrofitting projects [194], [36], [1].

5.5.5 Collaboration with Building Industry

Foster collaboration between accessibility experts, architects, designers, and builders to integrate accessibility features into private home designs. Encourage the building industry to prioritize accessibility during the planning and construction phases [195], [8], [1].

5.5.6 Accessible Technology and Innovations

Explore the use of assistive technologies and smart home solutions to enhance accessibility in private homes. This can include features like voice-controlled systems, home automation, or accessible applications that promote independent living [73].

5.5.7 Homeowner Engagement

Engage homeowners in the accessibility evaluation process. Encourage them to provide feedback, share their experiences, and participate in the evaluation of their homes' accessibility. This involvement can contribute to a more accurate assessment and help identify specific needs and challenges [9].

5.5.8 Collaboration with Disability Organizations

Partner with disability organizations and advocacy groups to provide resources, guidance, and support to homeowners. These organizations can offer expertise, access to user feedback, and practical insights on accessibility requirements [1], [9].

5.5.9 Design Professional Training

Incorporate accessibility training into the curriculum of design professionals such as architects, interior designers, and contractors. This ensures that future professionals are equipped with the knowledge and skills necessary to create accessible homes.

5.5.10 Building Code and Regulation Updates

Regularly review and update building codes and regulations to include more comprehensive accessibility requirements for private homes. Ensure that accessibility is considered not only for new constructions but also for renovation and retrofitting projects.

By implementing these strategies, it is possible to overcome accessibility measurement challenges in private homes and promote the creation of more accessible living environments for homeowners. It requires a collaborative effort involving homeowners, professionals, government agencies, and advocacy groups to prioritize and implement accessible design principles in residential settings.

5.6 What is the difference between accessibility measurement and accessibility evaluation of home?

The difference between accessibility measurement and accessibility evaluation of a private home is similar to that of a public building but adapted to the residential context:

5.6.1 Accessibility Measurement (Private Home)

Accessibility measurement in the context of a private home involves quantifying or assessing the level of accessibility based on specific criteria, metrics, or standards. It focuses on objectively evaluating the physical, sensory, or cognitive accessibility features and barriers present in the home. This could include elements such as entrance accessibility, door widths, interior layout, bathroom accessibility, and other physical aspects of the home that impact accessibility. Accessibility measurement provides a quantitative or qualitative understanding of the level of accessibility in the home, helping to identify areas that may need improvement [99], [111], [112], [196].

5.6.2 Accessibility Evaluation (Private Home)

Accessibility evaluation of a private home goes beyond measurement and involves a comprehensive assessment of the home's accessibility and its suitability for the specific needs of its occupants. It considers not only the physical features but also the usability, inclusiveness, and overall user experience within the home. Accessibility evaluation takes into account factors such as the functionality of the layout, ease of movement, adaptability of features, personalization of spaces, and the overall satisfaction and comfort of the occupants. It may also involve gathering input from the residents to understand their unique needs, challenges, and preferences related to accessibility.

The accessibility measurement focuses on objectively assessing the physical accessibility features of a private home, while accessibility evaluation takes a more comprehensive approach by considering usability, user experience, and the specific needs and preferences of the occupants. Accessibility evaluation provides a holistic understanding of the home's accessibility, identifying areas for improvement and ensuring that it meets the individual needs of its residents.

5.7 Accessibility evaluation challenges of home

Accessibility evaluation of private homes can present unique challenges. Here are some common challenges that evaluators may encounter

5.7.1 Privacy and Access Limitations

Conducting accessibility evaluations in private homes can be challenging due to privacy concerns and limitations on access. Unlike public buildings, private homes are personal spaces, and gaining access for evaluation purposes may require the cooperation and consent of the homeowners. Some homeowners may be hesitant to allow evaluators to assess their homes, which can impact the ability to conduct thorough evaluations [197].

5.7.2 Diverse Home Designs and Architectural Features

Private homes come in various designs, sizes, and architectural styles. Evaluators need to be adaptable and knowledgeable about different housing types to effectively evaluate their accessibility. The diverse nature of private homes can make it challenging to apply standardized evaluation criteria across all properties [132], [142], [112].

5.7.3 Limited Availability of Documentation

Unlike public buildings, private homes may not have readily available documentation or blueprints that provide detailed information about the home's design and construction. This lack of documentation can make it more challenging for evaluators to accurately assess the accessibility features and identify potential barriers [1].

5.7.4 Customization and Personalization

Private homes often reflect the preferences and needs of their owners, which can result in customized features or modifications. These customizations may impact the accessibility of the home, requiring evaluators to consider the specific adaptations made and their implications on overall accessibility.

5.7.5 Financial Constraints

Accessibility improvements in private homes are often the responsibility of the homeowners. Financial constraints may limit the extent to which accessibility modifications can be made, impacting the overall accessibility of the home. Evaluators need to be mindful of these limitations and provide practical recommendations that consider the homeowners' budgetary constraints.

5.7.6 User Perspectives and Input

Private homes are occupied by individuals or families, and their perspectives and input are crucial in evaluating accessibility. Gathering user feedback and understanding the specific needs and challenges of the occupants is essential but may present challenges in terms of engagement and communication.

5.7.7 Limited Accessibility Knowledge and Awareness

Homeowners may have limited knowledge about accessibility standards, guidelines, and best practices. This lack of awareness can influence their understanding of accessibility evaluations and their willingness to invest in accessibility improvements. Educating homeowners and raising awareness about the benefits of accessible design can help overcome this challenge. Addressing these challenges requires effective communication with homeowners, flexibility in evaluation methods, collaboration with accessibility experts, and an understanding of the unique aspects of each private home. By working closely with homeowners, evaluators can provide practical recommendations to improve accessibility and enhance the overall living experience for individuals with disabilities or mobility limitations .

5.8 How we can solve accessibility evaluation challenges of private home?

To address the accessibility evaluation challenges of private homes, consider the following strategies

5.8.1 Education and Awareness

Raise awareness among homeowners about the importance of accessibility evaluation in private homes. Educate them about the benefits of a comprehensive evaluation and how it can improve the overall accessibility and usability of their homes.

5.8.2 Accessibility Evaluation Guidelines

Develop guidelines or checklists specifically tailored for evaluating the accessibility of private homes. These guidelines can provide evaluators with a structured approach to assessing different aspects of accessibility, such as entrance accessibility, interior layout, bathroom accessibility, and other relevant features.

5.8.3 Qualified Accessibility Evaluators

Train and certify accessibility evaluators who specialize in private home assessments. Ensure that evaluators have the knowledge, skills, and experience necessary to evaluate accessibility in residential settings. This can involve providing training programs, certification processes, and ongoing professional development opportunities.

5.8.4 Collaboration with Homeowners

Foster collaboration and communication with homeowners during the evaluation process. Engage homeowners in discussions about their specific accessibility needs, challenges, and preferences. This collaboration can help evaluators gain valuable insights and ensure that the evaluation is tailored to the homeowner's unique circumstances.

5.8.5 User Feedback and Experiences

Seek input from individuals with disabilities and those who have experience living in accessible homes. Gather feedback on the usability, functionality, and overall accessibility of the home. This feedback can provide valuable insights and perspectives that enhance the accuracy and effectiveness of the evaluation.

5.8.6 Consideration of Universal Design Principles

Incorporate universal design principles into the evaluation process. Universal design aims to create environments that are accessible and usable by individuals of all abilities. Evaluators should consider how well the home adheres to these principles, such as flexibility, simplicity, and inclusiveness.

5.8.7 Technological Solutions

Utilize technology to support accessibility evaluations. Digital tools and software can assist evaluators in documenting and analyzing accessibility features, conducting virtual assessments, and simulating user experiences. These technological solutions can streamline the evaluation process and enhance accuracy.

5.8.8 Collaboration with Accessibility Experts

Collaborate with accessibility experts, occupational therapists, or other professionals specializing in home accessibility. These experts can provide valuable insights, guidance, and recommendations during the evaluation process, ensuring a comprehensive assessment of the home's accessibility.

5.8.9 Public Awareness and Advocacy

Increase public awareness about the importance of accessibility evaluations in private homes. Advocate for accessible design and encourage homeowners to prioritize accessibility in their homes. Promote the benefits of inclusive and accessible living environments.

By implementing these strategies, it is possible to overcome accessibility evaluation challenges in private homes and ensure that homeowners have access to comprehensive evaluations that address their specific accessibility needs.

5.9 How Artificial Intelligence models can help to solve accessibility measurement of private home challenges?

Artificial intelligence (AI) models can contribute to solving accessibility measurement challenges in private homes in the following ways

5.9.1 Image Analysis and Object Detection

AI models can analyze images or floor plans of private homes to detect and identify accessibility features. For example, they can identify grab bars in bathrooms, wheelchair ramps, or widened doorways. This can assist in evaluating the presence and quality of accessibility features in private homes.

5.9.2 Virtual Simulations and User Experience Testing

AI models can generate virtual simulations of private homes, allowing evaluators to virtually navigate and experience the accessibility features. These simulations can simulate different user scenarios, such as individuals with mobility impairments or sensory disabilities, to identify potential accessibility barriers and evaluate the effectiveness of existing features.

5.9.3 Personalized Accessibility Recommendations

AI models can provide personalized accessibility recommendations based on individual needs and preferences. By considering user profiles, such as specific mobility limitations or sensory impairments, models can suggest specific modifications or adaptations that would enhance the accessibility and usability of private homes for different individuals.

5.9.4 Natural Language Processing (NLP)

NLP techniques can be employed to analyze and extract information from textual documents, such as accessibility guidelines or best practices for private homes. AI models can interpret and understand the requirements and recommendations for accessible home design, providing evaluators with valuable guidance and insights.

5.9.5 Intelligent Assistants and Chatbots

AI-powered intelligent assistants or chatbots can provide information and guidance on accessibility features in private homes. They can assist homeowners in understanding accessibility requirements, suggesting modifications, and providing resources for creating more accessible living environments.

5.9.6 Data Analysis and Pattern Recognition

AI models can analyze data related to private homes, such as home characteristics, accessibility modifications, and user feedback. By training models on this data, they can recognize patterns and identify potential accessibility challenges or areas for improvement. This can aid evaluators in identifying common issues and prioritizing accessibility enhancements.

5.9.7 Collaboration with Accessibility Experts

AI models can facilitate collaboration with accessibility experts, allowing for their expertise to be incorporated into the evaluation process. By integrating expert knowledge into the models, they can provide more accurate and reliable accessibility assessments of private homes.

It is important to note that while AI models can assist in accessibility measurement, they should not replace human evaluators or user input. These models should be developed and trained using diverse and representative data to ensure their accuracy and effectiveness. Human expertise and evaluation remain crucial in interpreting the results generated by AI models and making informed decisions regarding accessibility improvements in private homes.

5.10 Background

Our research focuses on increasing the safety and independence of older adults at home by modifying their home environment. Rehabilitation can be provided in a variety of settings, including hospitals, private clinics, and communities such as homes. Helping people with disabilities live at home is a basic responsibility of modern society [37], [9]. Although, people with disabilities continue to be moved or institutionalized because of inaccessible housing. One strategy for solving this issue is to create more effective interventions to allow people with disabilities to live successfully at home, especially in their old age. Home modifications are generally used to help people with disabilities stay in the community [188]. The foundation of a home modification is the home evaluation [186]. The accessibility evaluation of the home begins with a comprehensive examination of the physical structure of the home, the homeowner's capacities, and the desired level of performance in recommendations aimed to increase the homeowner's safety when engaged in daily activities [175]. It takes time in order to collect data, schedule the client and other team members, integrate, write reports, information and communicate results. Home evaluations require in-depth and interactive experience [177], [176]. The process requires a strong knowledge base in disability, types of rehabilitation interventions, assistive technology in-depth knowledge, task adaptive strategies, interviewing skills, safety assessment, home building and remodeling methods. Technology-driven assessments have the capacity to improve efficiency and assist in guiding the practitioner by the data collection and decision-making processes. Smartphones and tablets, allow evaluators to take measurements directly with devices. Computer- assisted evaluations can potentially speed up the whole assessment process by guiding practitioners through the process[10, 12]. It ensures that important questions are asked, and irrelevant questions are skipped. Moreover, mobile technology is becoming increasingly important in health care research with a range of tools to support the practitioner.

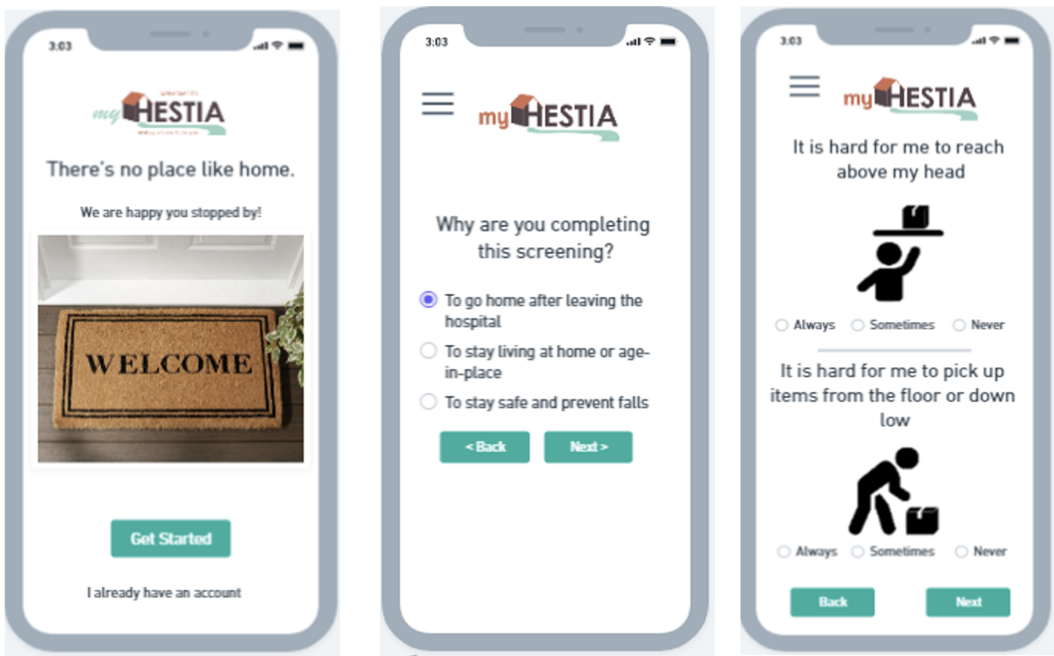
Technology-driven assessment through mobile applications (apps) improves home builders' decision-making and client outcomes [9]. Our research builds a prototype to prove the research concept. The prototype is a mobile application named myHESTIA, the Home Evaluation with a Strategic Triangulating Integrative Approach app. This application is a home safety assessment tool designed to facilitate aging-in-place and home integration outcomes. The aim is to meet the needs of the public and practitioners for a comprehensive and efficient assessment tool to guide the practitioner through the process of a home safety evaluation. The app is developed with an iterative approach integrating the preferences and needs of personal home evaluation providers.

The major issues of home evaluations are- time-consuming, data reliability, and standard scoring of accessibility. To solve all these issues, we propose to use a machine learning algorithm to do the home evaluation in a smarter way.

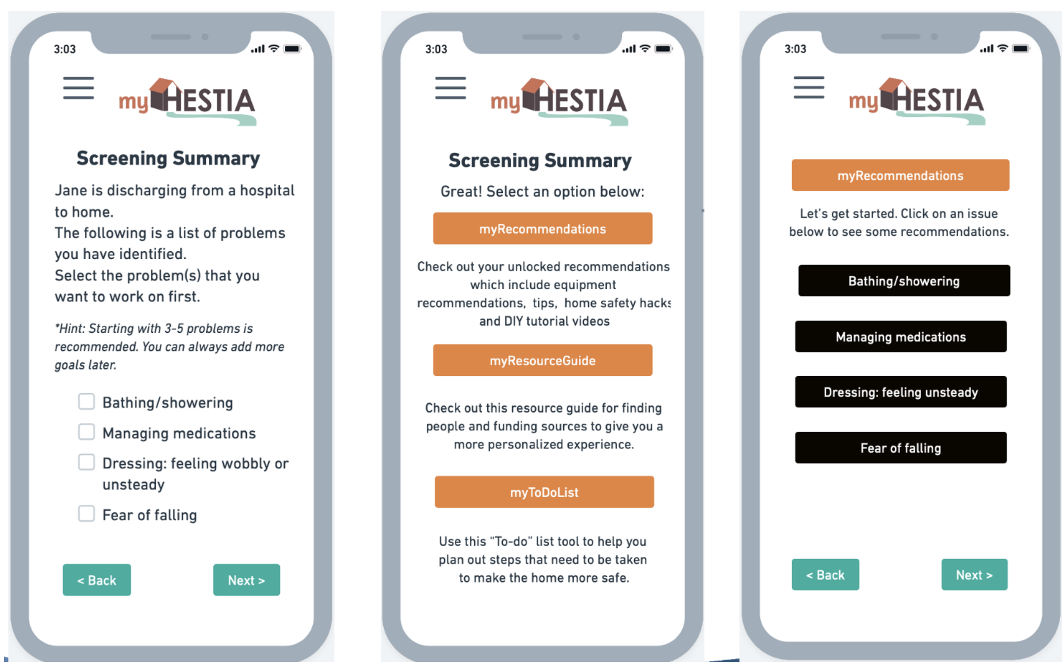
5.11 Methodology

The fundamental goal of our prototype is to enhance the reach of home modification solutions by providing a simplified and guided home safety assessment with individualized and prioritized recommendations. In our proposed solution the user first creates a profile. Based on the user profile personalizing information is displayed, that is most matched to the individual's specific accessibility needs. Users may choose to view summary reports with the information provided by other people with disabilities (who have shared personal accessibility assessments). The filtering data from a large set of questions will use the decision tree one of the most popular machine learning algorithms for decision making. This application gives a set of recommendations based on the evaluation. The recommendation has the videos to give suggestions to the users.

The machine learning models will be integrated to make the decision efficiently [20-26]. Now we don't have any defined scoring process for the accessibility assessment of



(a) myHESTIA UI - Questions [1]



(b) myHESTIA UI - Screening summary [1]

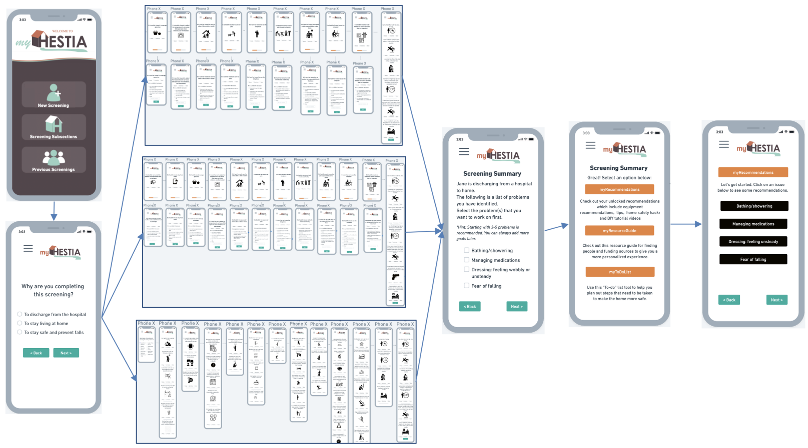


Figure 5.1: myHESTIA- AI based smarter reporting system [1]

the home. Establishing a reliable and standard scoring of a home evaluation is one of the main focuses for the future.

5.12 How Artificial Intelligence can help to generate automated reporting?

Data Analysis and Insights: AI algorithms can analyze large volumes of data quickly and efficiently. Techniques such as machine learning and statistical analysis can identify patterns, correlations, and anomalies within the data. By applying AI algorithms, reporting systems can automatically derive insights and summarize key findings from the data [137].

5.12.1 Visualization and Presentation

AI-powered reporting systems can generate visualizations and dashboards to present data in a clear and concise manner. This includes charts, graphs, and interactive visualizations that allow users to explore and understand the data better. AI can also assist in selecting appropriate visual representations based on the nature of the data and the target audience [151].

5.12.2 Report Personalization

AI can enable automated reporting systems to personalize reports based on individual user preferences. By leveraging user data, historical patterns, and machine learning algorithms, reports can be tailored to specific users or user groups. This customization can enhance the relevance and usefulness of the reports [174], [175], [177].

5.12.3 Contextual Understanding

AI can utilize natural language processing (NLP) to extract context and meaning from textual data. By understanding the context, AI algorithms can generate reports that are more accurate and relevant. For example, sentiment analysis can be employed to gauge customer sentiment from social media data and generate reports on customer satisfaction [56], [57], [58], [59].

5.12.4 Automated Report Scheduling and Delivery

AI-powered reporting systems can automate the scheduling and delivery of reports based on predefined frequencies or triggers. This ensures that reports are generated and distributed at the right time to the intended recipients. AI can also optimize the delivery format based on user preferences, such as email, web-based portals, or mobile apps [173], [174], [86], [176], [177].

5.12.5 Continuous Improvement and Learning

AI algorithms can learn from user interactions, feedback, and usage patterns to improve the quality and relevance of the automated reporting system over time. By continuously analyzing user behavior and preferences, AI can refine the reporting process and provide more valuable insights to users [133], [134], [135].

5.12.6 Predictive Analytics

AI can leverage predictive modeling techniques to forecast future outcomes based on historical data. By applying machine learning algorithms, AI can generate reports that provide predictions, forecasts, or recommendations. These reports empower decision-makers with insights into potential future scenarios and assist in proactive decision-making [144], [143].

5.12.7 Personalized Reporting

AI can enable the generation of personalized reports tailored to the needs and preferences of individual users. By analyzing user behavior, historical patterns, and preferences, AI algorithms can generate reports that are relevant and specific to each user. Personalized reporting enhances user engagement and increases the value of the reports [173], [176].

5.12.8 Real-time Reporting

AI can enable real-time or near-real-time reporting by continuously analyzing and processing streaming data. This allows for timely reporting and monitoring of dynamic systems or situations. Real-time reporting empowers decision-makers to respond promptly to emerging trends or issues.

By leveraging AI technologies, smart reporting can provide actionable insights, predictive capabilities, and personalized information to stakeholders. It enhances decision-making processes, facilitates data-driven strategies, and improves overall organizational performance.

5.13 The AI algorithms for smart reporting?

Smart reporting can benefit from various AI models depending on the specific requirements and data characteristics. Here are some AI models commonly used for smart reporting [144], [173].

5.13.1 Natural Language Processing (NLP) Models

NLP models are crucial for smart reporting, enabling understanding and processing of textual data. Techniques such as text classification, named entity recognition, sentiment analysis, and topic modeling can be employed to extract valuable insights from textual sources. Pretrained models like BERT, GPT, or ELMO can be fine-tuned for specific NLP tasks in smart reporting [134], [135] .

5.13.2 Machine Learning Models

Machine learning algorithms can be applied to analyze and predict patterns in data. Models like decision trees, random forests, support vector machines (SVM), or gradient boosting algorithms (e.g., XGBoost, LightGBM) can be used for classification, regression, or anomaly detection tasks. These models help identify trends, make predictions, and generate actionable insights in smart reporting [147], [157], [156], [198].

5.13.3 Deep Learning Models

Deep learning models, particularly deep neural networks, excel at capturing complex patterns and relationships in data. Convolutional Neural Networks (CNNs) are effective for image data, while Recurrent Neural Networks (RNNs) and Transformers are well-suited for sequential and text data. Deep learning models can provide advanced capabilities in image recognition, sentiment analysis, text generation, and other tasks relevant to smart reporting [92], [160].

5.13.4 Generative Models

Generative models such as Generative Adversarial Networks (GANs) or Variational Autoencoders (VAEs) can be employed for tasks like data augmentation or generating synthetic data. These models can help address data scarcity issues and enhance the quality and diversity of available data for smart reporting [144], [147].

5.13.5 Time Series Models

Time series forecasting is essential in smart reporting, particularly for analyzing trends, making predictions, and identifying anomalies in time-dependent data. Models like Autoregressive Integrated Moving Average (ARIMA), Seasonal Decomposition of Time Series (STL), or recurrent neural networks (RNNs) with Long Short-Term Memory (LSTM) cells are commonly used for time series analysis and forecasting.

5.13.6 Reinforcement Learning Models

Reinforcement learning (RL) models can assist in decision-making processes and optimize actions based on rewards or penalties. In smart reporting, RL can be used for dynamic reporting scenarios, where the AI agent learns and adapts reporting strategies based on user feedback, interaction, or changing conditions [147], [58], [149], [151], [150].

5.13.7 Ensemble Models

Ensemble models combine multiple individual models to generate more accurate and robust predictions. Techniques like bagging, boosting, or stacking can be employed to create powerful ensemble models for smart reporting, improving overall performance and reliability [150].

It's important to consider the specific requirements, data characteristics, and the problem domain when selecting AI models for smart reporting. It may involve a combination of different models and techniques tailored to the specific reporting needs and objectives.

5.14 What ethical considerations should be taken into account when using AI for private home accessibility measurement, such as privacy, bias mitigation, and transparency in decision-making processes?

When using AI for private home accessibility measurement, it is important to consider and address various ethical considerations, including.

5.14.1 Privacy

Ensure that the data collected and processed by AI systems for home accessibility measurement is handled with utmost care for privacy. Minimize the collection of personally identifiable information (PII) and implement robust security measures to protect user data from unauthorized access or breaches [136].

5.14.2 Informed Consent

Obtain informed consent from homeowners or occupants before collecting and using their data for accessibility measurement purposes. Clearly communicate the purpose, methods, and potential risks associated with data collection, and provide options for individuals to opt-in or opt-out of data sharing [133].

5.14.3 Bias Mitigation

Address potential biases in AI systems used for home accessibility measurement. Biases can arise from biased training data, algorithmic biases, or inherent limitations of the system. Regularly evaluate and mitigate biases to ensure fair and equitable accessibility assessments for individuals with diverse disabilities or accessibility needs [134].

5.14.4 Transparency and Explainability

AI systems used for home accessibility measurement should be transparent and explainable. Users should have visibility into how the system makes decisions and assessments regarding accessibility. Provide clear explanations of how data is collected, processed, and used to generate accessibility measurements. This transparency helps build trust and enables homeowners or occupants to understand and verify the results [181].

5.14.5 Accountability

Establish clear lines of accountability for the AI system's performance and outcomes. Define roles and responsibilities for system developers, operators, and stakeholders to ensure appropriate oversight, auditing, and addressing of any issues or concerns that may arise [178].

5.14.6 User Autonomy and Control

Prioritize user autonomy and control over their own home accessibility data. Allow homeowners or occupants to have control over the data collected, its use, and the ability to modify or delete their data. Respect user preferences and decisions regarding data sharing and system usage [197].

5.14.7 Accessibility and Inclusivity

Ensure that the AI system itself is accessible and usable by individuals with disabilities or accessibility needs. Consider accessibility standards and guidelines during the design and development process to make the AI system inclusive and usable for all users [2].

5.14.8 Ongoing Evaluation and Improvement

Continuously evaluate the performance, accuracy, and impact of the AI system for home accessibility measurement. Incorporate feedback from homeowners, occupants, and stakeholders to identify and address any ethical concerns, biases, or limitations of the system. Strive for continuous improvement and iterative development to enhance the ethical and inclusive use of AI for private home accessibility measurement [199], [200], [201], [202].

By considering these ethical considerations, AI-based systems for private home accessibility measurement can promote privacy, fairness, transparency, user autonomy, and inclusivity while minimizing potential risks and biases associated with data privacy and decision-making processes [203], [204].

Case 1: No user info+ No home info Case 2: No user info+ Some home info Case 3: No user info+ Details home info Case 4:Some user info+ No home info Case 5: Some user info+ Some home info Case 6: Some user info+ Details home info Case 7:Detail user info+ No home info Case 8:Detail user info+ Some home info Case 9:Detail user info+ Details home info Explainable AI, also known as interpretable AI or transparent AI, refers to the development of artificial intelligence systems that can provide understandable explanations for their actions and decision-making processes.

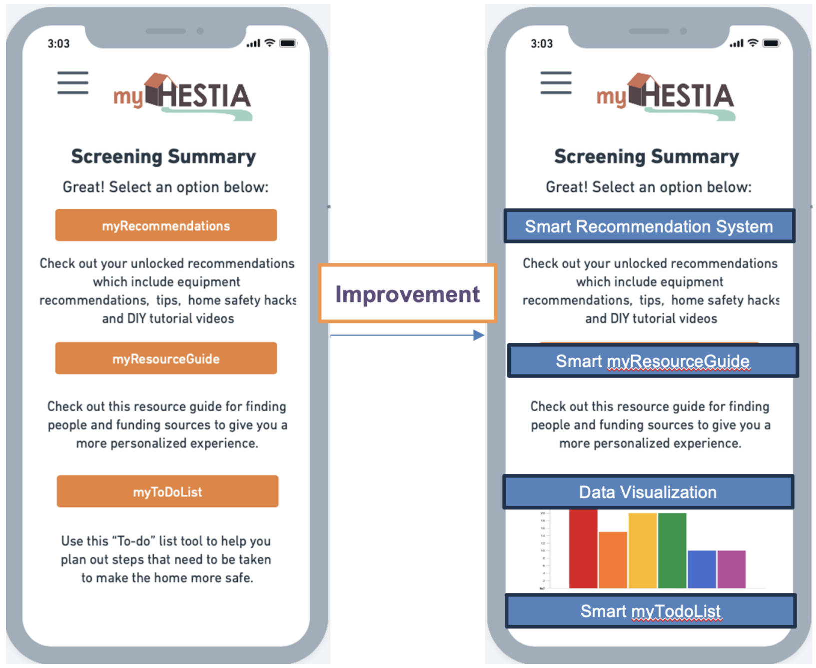


Figure 5.2: myHESTIA- comparison between current reporting and AI based smarter reporting system

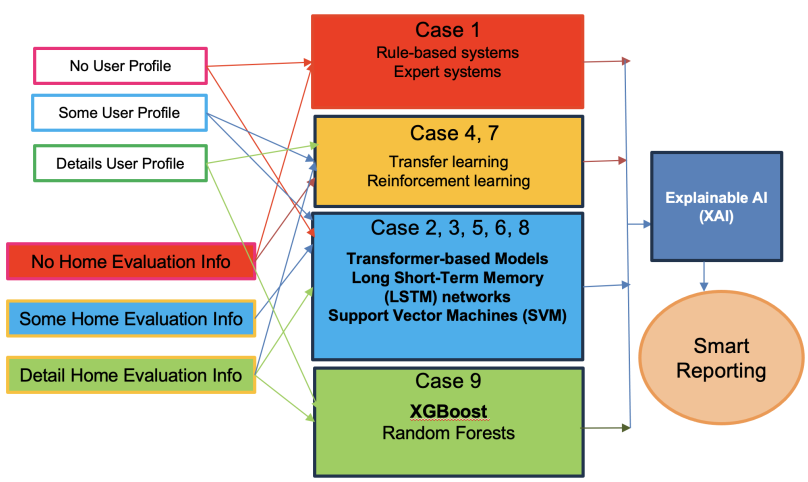


Figure 5.3: myHESTIA- AI based choice for generating smarter report [1]

Chapter 6
Conclusion

6.1 Summary

The research conducted focuses on harnessing the power of artificial intelligence (AI) and machine learning (ML) algorithms to enhance accessibility for individuals with disabilities (PwD) in three key areas: public buildings, homes, and medical devices. The primary objective is to improve the accuracy, reliability, and effectiveness of accessibility evaluation systems by utilizing advanced technologies.

In public buildings, the challenge lies in developing an accessibility evaluation system that is accurate, comprehensive, and reliable. AI can play a pivotal role by analyzing data, identifying potential barriers, and assessing the accessibility of various features within buildings. The developed application for data collection is reliable and efficient by integrating both PwD and expert information. By training AI algorithms on relevant data, the system can acquire the ability to make more accurate predictions about the accessibility of different spaces. This knowledge can then assist policymakers and architects in designing more inclusive environments. For private spaces such as homes, it is crucial to have an accessibility evaluation system that focuses on individual needs. The developed data collection tool myHESTIA and by the implementation of machine learning-based intelligent systems could make it feasible to evaluate the accessibility of individual homes and generate intelligent reporting based on specific requirements and preferences. This personalized approach allows for the identification of barriers and the provision of recommendations for modifications or assistive technologies that can enhance accessibility and independence for PwD within their own living spaces. The research also addresses the intelligent evaluation of healthcare devices within the home environment. Many PwD rely on medical devices for their daily activities, making it essential to ensure the accessibility and usability of these devices. The developed

MED-Audit application and using data from MED-Audit, AI can be utilized to evaluate the accessibility features of medical devices, offer the best medical devices for an individual, give recommendations for improvement, and even measure their effectiveness in meeting the needs of PwD.

Overall, the objective of this research is to improve the accuracy and reliability of accessibility evaluation systems by leveraging AI and ML technologies. By doing so, it seeks to enhance the quality of life for individuals with disabilities by enabling greater independence, promoting social inclusion, and facilitating better accessibility in public buildings, private homes, and medical devices.

6.2 Contributions

This research contributes to improving medical device accessibility measurement and making a better choice to purchase medical devices for people with disabilities. The developed MED-Audit application (evaluation questions are for device use, a total of 177 questions, and accessibility features a total of 981 questions and user ratings for the 100 medical devices based on user answers) with future integration of ML models will contribute to establishing a reliable and valid evaluation. The users do not have to answer unnecessary questions or skip the questions. It will save user time significantly and improve the accuracy of device scoring. The scoring system includes -impairment categories, expert-knowledge matrices – correlated device features, and the scoring algorithm. The ML model logistic regression will be used; it will work based on statistical rating data analysis [173], [158], [159], [160], [92], [198]. We believe this research will significantly improve the existing scoring algorithm's accuracy.

For improving public building accessibility evaluation and measurement, this study introduces ARB, a mobile application-based solution that offers a robust, efficient, and valid approach to measuring accessibility. The proposed solution includes various components such as AccessSound, AccessLight, AccessRuler, AccessSlope, and AccessTools, collectively enhancing existing accessibility measurement methods. By leveraging intelligent systems powered by AI algorithms, ARB significantly improves the overall accessibility measurement system for buildings, benefiting the wider community and promoting independence for people with disabilities (PwD). One key aspect ARB addresses is consistency across different mobile devices, ensuring accurate interpretation and measurement of the built environment. Rehabilitation researchers and application developers must utilize mobile device sensors to recognize the inherent variability among measurements collected by different device models and versions.

Moreover, The myHESTIA solution is designed to cater to the needs of individuals who require assistive technology to support independent living in their homes, particularly those with new or worsening disabilities. This accessible solution can be utilized by a wide range of stakeholders, including people with disabilities, caregivers, handymen, neighbors, nursing aids, and community health workers, all of whom are interested in promoting improved independent living outcomes.

The development of myHESTIA involves an iterative refinement process to ensure that the app is innovative, user-friendly, and scalable. It is designed to be accessible to individuals without extensive knowledge of health conditions, assistive technology, or independent living. The solution leverages a comprehensive taxonomy and matrix that have been carefully developed and tested. These tools allow for the prediction of problem areas based on factors such as health conditions, everyday tasks, and environmental factors. The solution aims to expand the reach of home modification solutions by offering a simplified and guided home safety assessment. It provides personalized and prioritized suggestions for potential interventions based on the identified wants and needs of individuals with disabilities. The solution's smarter reporting system delivers simplified guidance on basic home modification interventions and generates an interactive report for users. The myHESTIA solution contributes to the accessibility and effectiveness of home modification solutions by providing a user-friendly platform that facilitates personalized home safety assessments and interventions. It aims to empower individuals with disabilities to make informed decisions about their living environments and enhance their overall independent living experience.

This research focuses on developing assessment tools to measure the accessibility of public buildings, homes, and products for individuals with disabilities. These assessment tools include software-based solutions designed to evaluate the accessibility of public buildings and home environments, and medical devices. Additionally, the research evaluates the impact of providing accessibility information and labeling tailored explicitly for PwD. The outcomes of this research highlight the significance of public building accessibility, accessible homes, and medical technology, as well as the importance of providing relevant accessibility information to individuals with disabilities. The results demonstrate the positive impact that accessible environments and products can have on the lives of people with disabilities, emphasizing the need for increased accessibility in these areas.

6.3 Future Works

In the realm of medical device accessibility, the integration of an AI-based analysis model will facilitate the selection of the most suitable medical devices. This integration will incorporate user profile information to enhance evaluation and provide more accurate recommendations for the best medical devices.

Integrating an AI algorithm model in the ARB application aims to enhance the public building evaluation system. This solution will be compatible with various types of devices and will incorporate user profiles, making the evaluation process more personalized and effective.

Integrating an AI-based, more innovative reporting system will further improve home accessibility. This system will enhance personalized questionnaires by leveraging user profile data, ensuring the evaluation process is tailored to individual needs and preferences.

REFERENCES

[1] "R2d2 lab," *R2D2 lab, https://uwm.edu/r2d2/projects/.*

[2] S. T. D. R. O. S. D. S. I. A. Sayeda Farzana Aktar, Mason Dennis Drake, "A machine learning-based approach to enhance the accuracy of sound measurements in ios devices for accessibility applications," 2023.

[3] S. F. A. D. R. O. S. D. S. I. A. Mason Dennis Drake, Steven C. Sizer, "myaccesstools: Validation of impairment-weighted scores," 2023.

[4] K. S. A. M. D. D. L. M. O. R. O. S. Sayeda Farzana Aktar, Shiyu Tian and S. I. Ahamed, "Mobile appication based solution for building accessibility assessment for comprehensive and personalized assessment," 2023.

[5] D. Williams, H. Ding, J. Awebwa, D. Williams, S. I. Ahamed, R. Mendonca, and R. O. Smith, "1math, stat. and comp. sci. department, marquette university, milwaukee, wi 2occupational therapy, temple university, philadelphia, pa 3r2d2 center, university of wisconsin-milwaukee, milwaukee, wi,"

[6] R. O. Smith, K. Barnekow, M. R. Lemke, R. Mendonca, M. Winter, T. Schwanke, and J. M. Winters, "Development of the medical equipment device accessibility and universal design information tool," *Medical instrumentation: Accessibility and usability considerations*, p. 474, 2006.

[7] E. M. Smith, R. J. Gowran, H. Mannan, B. Donnelly, L. Alvarez, D. Bell, S. Contepomi, L. Ennion, E.-J. Hoogerwerf, T. Howe, *et al.*, "Enabling appropriate personnel skill-mix for progressive realization of equitable access to assistive technology," *Disability and Rehabilitation: Assistive Technology*, vol. 13, no. 5, pp. 445–453, 2018.

[8] "Unitednationsconventionontherightsofpersonswithdisabilities," *UnitedNationsConventionontheRightsofPersonswithDisabilities. Retrieved from https://www.un.org/development/desa/disabilities/convention-on-the- rights-of-persons-with-disabilities.html.*

[9] N. D. Pickens, R. Mendonca, S. P. Burns, and R. O. Smith, "Home safety evaluation–getting it right," *Disability and Rehabilitation: Assistive Technology*, vol. 17, no. 6, pp. 652–657, 2022.

[10] "Who," *WHO, https://www.who.int/news-room/fact-sheets/detail/rehabilitation.*

[11] Q. M. Obiedat, *Interrater Reliability of the AccessTools Assessment with Novice Raters.* PhD thesis, The University of Wisconsin-Milwaukee, 2022.

[12] C. A. Okoro, N. D. Hollis, A. C. Cyrus, and S. Griffin-Blake, "Prevalence of disabilities and health care access by disability status and type among adults—united states, 2016," *Morbidity and Mortality Weekly Report*, vol. 67, no. 32, p. 882, 2018.

[13] J. Wu, W. Hu, J. Coelho, P. Nitu, H. R. Paul, P. Madiraju, R. O. Smith, and S. I. Ahamed, "Identifying buildings with ramp entrances using convolutional neural networks," in *2019 IEEE 43rd Annual Computer Software and Applications Conference (COMPSAC)*, vol. 2, pp. 74–79, IEEE, 2019.

[14] S. H. Landers, "The case for "connected health" at home," *OPTIMIZING HOME HEALTH CARE: ENHANCED VALUE AND IMPROVED OUTCOMES*, p. 27, 2013.

[15] W. ZAFIRAU, "Optimizing home health care: Enhanced value and improved outcomes," 2013.

[16] K. Martens and A. Golub, "A justice-theoretic exploration of accessibility measures. accessibility analysis and transport planning: Challenges for europe and north america. kt geurs, kj krizek and a. reggiani," 2012.

[17] S. K. Kane, C. Jayant, J. O. Wobbrock, and R. E. Ladner, "Freedom to roam: a study of mobile device adoption and accessibility for people with visual and motor disabilities," in *Proceedings of the 11th international ACM SIGACCESS conference on Computers and accessibility*, pp. 115–122, 2009.

[18] E. Capezuti, M. L. Malone, A. Khan, and S. L. Baumann, *The encyclopedia of elder care: The comprehensive resource on geriatric health and social care*. Springer Publishing Company, 2017.

[19] F. Di Porto and G. Ghidini, ""i access your data, you access mine": Requiring data reciprocity in payment services," *IIC-International Review of Intellectual Property and Competition Law*, vol. 51, no. 3, pp. 307–329, 2020.

[20] H. N. Kim, T. L. Smith-Jackson, and B. M. Kleiner, "Accessible haptic user interface design approach for users with visual impairments," *Universal access in the information society*, vol. 13, pp. 415–437, 2014.

[21] N. W. Kim, S. C. Joyner, A. Riegelhuth, and Y. Kim, "Accessible visualization: Design space, opportunities, and challenges," in *Computer Graphics Forum*, vol. 40, pp. 173–188, Wiley Online Library, 2021.

[22] M. Mukhiddinov and S.-Y. Kim, "A systematic literature review on the automatic creation of tactile graphics for the blind and visually impaired," *Processes*, vol. 9, no. 10, p. 1726, 2021.

[23] C. Jung, S. Mehta, A. Kulkarni, Y. Zhao, and Y.-S. Kim, "Communicating visualizations without visuals: Investigation of visualization alternative text for people with visual impairments," *IEEE transactions on visualization and computer graphics*, vol. 28, no. 1, pp. 1095–1105, 2021.

[24] J. C. B. Damaceno, Rafael Jeferson Pezzuto and J. P. Mena-Chalco, "Accessible haptic user interface design approach for users with visual impairments," *Mobile device accessibility for the visually impaired: problems mapping and recommendations*, pp. 421–435, 2018.

[25] R. J. P. Damaceno, J. C. Braga, and J. P. Mena-Chalco, "Mobile device accessibility for the visually impaired: problems mapping and recommendations," *Universal Access in the Information Society*, vol. 17, pp. 421–435, 2018.

[26] T. G. J. M. W. C. M. P. F. S. A. S. M. A. Siebra, Clauirton and F. Florentin, "Accessible haptic user interface design approach for users with visual impairments," *Usability requirements for mobile accessibility: a study on the vision impairment*, pp. 384–389, 2015.

[27] D. T. C. O. Revilla, Melanie and G. Loewe, "Do online access panels need to adapt surveys for mobile devices?," no. 5, p. 26, 2016.

[28] K. Martens, "Why accessibility measurement is not merely an option, but an absolute necessity," *Accessibility Tools and Their Applications. New York and London: Routledge*, 2019.

[29] "Building research establishment," *https://www.bregroup.com/*.

[30] "Public rights-of-way," *Access Board. "Public Rights-of-Way." Retrieved from https://www.access-board.gov/guidelines-and-standards/streets- sidewalks/public-rights-of-way*.

[31] N. Bitterman, "Design of medical devices—a home perspective," *European journal of internal medicine*, vol. 22, no. 1, pp. 39–42, 2011.

[32] N. M. O. M. Chaniaud, Noémie and E. Loup-Escande, "Effect of prior health knowledge on the usability of two home medical devices: Usability study," *JMIR mHealth and uHealth 8*, vol. e17983, no. 9, 2020.

[33] M. W.-B. Fu, Maggie and E. Tanno, "Medical devices in the home: a unique challenge for the fda," *JMIR mHealth and uHealth 8*, vol. 41, no. 3, pp. 361–365, 2012.

[34] S. F. A. D. R. O. S. Rochelle J. Mendonca, Maysam M. Ardehali, "Interrater reliability of the med-audit (medical equipment device – accessibility and universal design information tool)," 2023.

[35] F. G. Barbotte, Eric and N. Chau, "Prevalence of impairments, disabilities, handicaps and quality of life in the general population: a review of recent literature," *Bulletin of the World Health Organization*, vol. 79, no. 11, pp. 1047–1055, 2001.

[36] "U.s. census bureau (2004). disability status: 2000 – census 2000 brief," *https://web.archive.org/web/20041106151812/http://www.census.gov/hhes/www/disable/disabstat2k/table1.html (Archived Version)*.

[37] L. M. S. R. O. W. M. . M. R. Pizur-Barnekow, K., "Med-audit impairment categories: Working towards mapping ami usability," 2005.

[38] R. O. Smith, *OT FACT, version 2.0 [Computer software]: American Occupational Therapy Association*. American Occupational Therapy Association, 1995.

[39] "Vital and health statistics, summary health statistics for u.s. adults: National health interview survey," *United States Department of Health and Human Services (July 2004)*, vol. 10, no. 222, 2002.

[40] R. O. Smith, "Otfact: Multi-level performance-oriented software with an assistive technology outcomes assessment protocol," *Technology and Disability*, vol. 14, no. 3, pp. 133–139, 2002.

[41] J.-F. Levesque, M. F. Harris, and G. Russell, "Patient-centred access to health care: conceptualising access at the interface of health systems and populations," *International journal for equity in health*, vol. 12, pp. 1–9, 2013.

[42] A. Kumar, A. Chourasia, *et al.*, "Blind navigation system using artificial intelligence," *International research journal of engineering and technology (IRJET)*, vol. 5, no. 3, pp. 601–605, 2018.

[43] K. Kumar, B. Champaty, K. Uvanesh, R. Chachan, K. Pal, and A. Anis, "Development of an ultrasonic cane as a navigation aid for the blind people," in *2014 international conference on control, instrumentation, communication and computational technologies (ICCICCT)*, pp. 475–479, IEEE, 2014.

[44] F. Wong, R. Nagarajan, and S. Yaacob, "Application of stereovision in a navigation aid for blind people," in *Fourth international conference on information, communications and signal processing, 2003 and the fourth Pacific Rim conference on multimedia. Proceedings of the 2003 joint*, vol. 2, pp. 734–737, IEEE, 2003.

[45] N. W. Moon, P. M. Baker, and K. Goughnour, "Designing wearable technologies for users with disabilities: Accessibility, usability, and connectivity factors," *Journal of Rehabilitation and Assistive Technologies Engineering*, vol. 6, p. 2055668319862137, 2019.

[46] A. Savidis and C. Stephanidis, "Unified user interface design: designing universally accessible interactions," *Interacting with computers*, vol. 16, no. 2, pp. 243–270, 2004.

[47] R. Miñón, L. Moreno, P. Martínez, and J. Abascal, "An approach to the integration of accessibility requirements into a user interface development method," *Science of Computer Programming*, vol. 86, pp. 58–73, 2014.

[48] S. Iwarsson and A. Ståhl, "Accessibility, usability and universal design—positioning and definition of concepts describing person-environment relationships," *Disability and rehabilitation*, vol. 25, no. 2, pp. 57–66, 2003.

[49] H. Persson, H. Åhman, A. A. Yngling, and J. Gulliksen, "Universal design, inclusive design, accessible design, design for all: different concepts—one goal? on the

concept of accessibility—historical, methodological and philosophical aspects," *Universal Access in the Information Society*, vol. 14, pp. 505–526, 2015.

[50] S. Burgstahler, *Equal access: Universal design of instruction.* DO-IT, University of Washington, 2008.

[51] S. Baradaran and F. Ramjerdi, "Performance of accessibility measures in europe," *Journal of transportation and statistics*, vol. 4, no. 2/3, pp. 31–48, 2001.

[52] R. O. Smith, *Sensitivity analysis of traditional and Trichotomous Tailored Sub-branching Scoring (TTSS) scales.* The University of Wisconsin-Madison, 1993.

[53] D. P. Huttenlocher and S. Ullman, "Object recognition using alignment," in *Proceedings of the DARPA Image Understanding Workshop*, pp. 370–380, 1987.

[54] K. Grauman and B. Leibe, *Visual object recognition.* No. 11, Morgan & Claypool Publishers, 2011.

[55] M. Danilevsky, K. Qian, R. Aharonov, Y. Katsis, B. Kawas, and P. Sen, "A survey of the state of explainable ai for natural language processing," *arXiv preprint arXiv:2010.00711*, 2020.

[56] L. Deng and Y. Liu, *Deep learning in natural language processing.* Springer, 2018.

[57] R. Dale, H. Moisl, and H. Somers, *Handbook of natural language processing.* CRC press, 2000.

[58] E. D. Liddy, "Natural language processing," 2001.

[59] S. Bird, E. Klein, and E. Loper, *Natural language processing with Python: analyzing text with the natural language toolkit.* " O'Reilly Media, Inc.", 2009.

[60] A. Bunt, C. Conati, and J. McGrenere, "Mixed-initiative interface personalization as a case study in usable ai," *AI Magazine*, vol. 30, no. 4, pp. 58–58, 2009.

[61] D. Billsus, C. A. Brunk, C. Evans, B. Gladish, and M. Pazzani, "Adaptive interfaces for ubiquitous web access," *Communications of the ACM*, vol. 45, no. 5, pp. 34–38, 2002.

[62] W. S. Sayed, A. M. Noeman, A. Abdellatif, M. Abdelrazek, M. G. Badawy, A. Hamed, and S. El-Tantawy, "Ai-based adaptive personalized content presentation and exercises navigation for an effective and engaging e-learning platform," *Multimedia Tools and Applications*, vol. 82, no. 3, pp. 3303–3333, 2023.

[63] A. H. Sapci and H. A. Sapci, "Innovative assisted living tools, remote monitoring technologies, artificial intelligence-driven solutions, and robotic systems for aging societies: systematic review," *JMIR aging*, vol. 2, no. 2, p. e15429, 2019.

[64] M. P. Kantipudi, C. J. Moses, R. Aluvalu, and S. Kumar, "Remote patient monitoring using iot, cloud computing and ai," *Hybrid Artificial Intelligence and IoT in Healthcare*, pp. 51–74, 2021.

[65] M. Alshamrani, "Iot and artificial intelligence implementations for remote healthcare monitoring systems: A survey," *Journal of King Saud University-Computer and Information Sciences*, vol. 34, no. 8, pp. 4687–4701, 2022.

[66] C. Bhat, S. Handy, K. Kockelman, H. Mahmassani, Q. Chen, I. Srour, L. Weston, *et al.*, "Assessment of accessibility measures," *Work*, vol. 7, pp. 4938–3, 2001.

[67] R. Smith, "Otfact: Software system for integrating and reporting occupational therapy functional assessment v1. 1.[computer software]," 1992.

[68] R. O. Smith, J. Hinkens, G. C. Vanderheiden, K. L. Rust, *et al.*, "Occupational therapy functional assessment compilation tool (ot fact)," *Journal of Rehabilitation Research and Development*, vol. 30, p. 136, 1994.

[69] M. D. Hightower-Vandamm, "Future ot—fact or fancy," *Canadian Journal of Occupational Therapy*, vol. 46, no. 4, pp. 139–142, 1979.

[70] R. O. Smith, "Ot fact application in mental health: An update," *Assessments in Occupational Therapy Mental Health*, p. 309.

[71] R. Smith, "Ot fact, version 2.0, version 2.03," *Computer software and manual]. Rockville, MD: American Occupational Therapy Association Inc*, 1998.

[72] D. Williams, N. Johnson, A. K. Saha, N. Spaeth, T. Snyder, D. Tomashek, S. I. Ahamed, and R. O. Smith, "xfact: Developing usable surveys for accessibility purposes," in *2016 Rehabilitation Engineering and Assistive Technology Society of North America National Conference*, 2016.

[73] D. Williams, A. S. Kumar, H. Domke, N. Spaeth, D. Tomashek, S. I. Ahamed, and R. O. Smith, "A mobile method for determining access ratings for the built environment,"

[74] C. T. Berube, *The x factor: Personality traits of exceptional science teachers.* IAP, 2010.

[75] L. Scherwitz, R. Mckelvain, C. Laman, J. Patterson, L. Dutton, S. Yusim, J. Lester, I. Kraft, D. Rochelle, and R. Leachman, "Type a behavior, self-involvement, and coronary atherosclerosis," *Psychosomatic Medicine*, vol. 45, no. 1, pp. 47–57, 1983.

[76] R. J. Mendonca, L. M. O'Donnell, and R. O. Smith, "Feasibility analysis: Med-audit (medical equipment device–accessibility and universal design information tool)," 2007.

[77] T. L. Rochelle, S. M. Shardlow, S. H. Ng, *et al.*, "Using the theory of planned behaviour to explain use of traditional chinese medicine among hong kong chinese in britain," *Evidence-Based Complementary and Alternative Medicine*, vol. 2015, 2015.

[78] R. J. Mendonca, L. M. O'Donnell, and R. O. Smith, "Resna annual conference-2021,"

[79] M. Lydon-Rochelle, V. L. Holt, D. P. Martin, and T. R. Easterling, "Association between method of delivery and maternal rehospitalization," *Jama*, vol. 283, no. 18, pp. 2411–2416, 2000.

[80] N. Negar, D. Williams, J. Schwartz, S. I. Ahamed, and R. O. Smith, "Smartphone-based light intensity calculation application for accessibility measurement," in *Proceedings of the RESNA Annual Conference, Indianapolis, IN, USA*, pp. 11–15, 2014.

[81] A. Hamraie, *Building access: Universal design and the politics of disability*. U of Minnesota Press, 2017.

[82] J. Balado, L. Díaz-Vilariño, P. Arias, and M. Soilán, "Automatic building accessibility diagnosis from point clouds," *Automation in construction*, vol. 82, pp. 103–111, 2017.

[83] P. Honohan, "Measuring microfinance access: Building on existing cross-country data," *Available at SSRN 753568*, 2005.

[84] N. Pasaogullari and N. Doratli, "Measuring accessibility and utilization of public spaces in famagusta," *Cities*, vol. 21, no. 3, pp. 225–232, 2004.

[85] C. Liddy, M. S. Rowan, A. Afkham, J. Maranger, and E. Keely, "Building access to specialist care through e-consultation," *Open Medicine*, vol. 7, no. 1, p. e1, 2013.

[86] A. Holl, "Twenty years of accessibility improvements. the case of the spanish motorway building programme," *Journal of Transport Geography*, vol. 15, no. 4, pp. 286–297, 2007.

[87] N. Thapar, G. Warner, M.-L. Drainoni, S. R. Williams, H. Ditchfield, J. Wierbicky, and S. Nesathurai, "A pilot study of functional access to public buildings and facilities for persons with impairments," *Disability and Rehabilitation*, vol. 26, no. 5, pp. 280–289, 2004.

[88] F. Alonso, "The benefits of building barrier-free: a contingent valuation of accessibility as an attribute of housing," *European Journal of Housing Policy*, vol. 2, no. 1, pp. 25–44, 2002.

[89] S. M. Foster, "Analysis of spatial patterns in buildings (access analysis) as an insight into social structure: examples from the scottish atlantic iron age," *Antiquity*, vol. 63, no. 238, pp. 40–50, 1989.

[90] H. Wang, J. Cao, Y. Zhang, H. Wang, J. Cao, and Y. Zhang, "Building access control policy model for privacy preserving and testing policy conflicting problems," *Access Control Management in Cloud Environments*, pp. 225–247, 2020.

[91] D. Evans and D. M. Eyers, "Efficient data tagging for managing privacy in the internet of things," in *2012 IEEE International Conference on Green Computing and Communications*, pp. 244–248, IEEE, 2012.

[92] G. Chen and F. Rahman, "Analyzing privacy designs of mobile social networking applications," in *2008 IEEE/IFIP International Conference on Embedded and Ubiquitous Computing*, vol. 2, pp. 83–88, IEEE, 2008.

[93] J.-W. Byun and N. Li, "Purpose based access control for privacy protection in relational database systems," *The VLDB Journal*, vol. 17, pp. 603–619, 2008.

[94] M. S. Z. Nyunt, F. K. Shuvo, J. Y. Eng, K. B. Yap, S. Scherer, L. M. Hee, S. P. Chan, and T. P. Ng, "Objective and subjective measures of neighborhood environment (ne): relationships with transportation physical activity among older persons," *International journal of behavioral nutrition and physical activity*, vol. 12, no. 1, pp. 1–10, 2015.

[95] Z. Gou, S. S.-Y. Lau, and F. Chen, "Subjective and objective evaluation of the thermal environment in a three-star green office building in china," *Indoor and Built Environment*, vol. 21, no. 3, pp. 412–422, 2012.

[96] S. Lotfi and M. J. Koohsari, "Analyzing accessibility dimension of urban quality of life: Where urban designers face duality between subjective and objective reading of place," *Social Indicators Research*, vol. 94, pp. 417–435, 2009.

[97] B. Lee, P. Waddell, L. Wang, R. M. Pendyala, and R. ECG252, "Operationalizing time-space prism accessibility in a building-level residential choice model," in *Proceedings of the 88th Annual Meeting of the TRB*, Citeseer, 2009.

[98] D. Williams, N. Johnson, O. C. Bangole, M. K. Hasan, D. Tomashek, S. I. Ahamed, and R. O. Smith, "Access tools: Developing a usable smartphone-based tool for determining building accessibility," in *2015 Rehabilitation Engineering and Assistive Technology Society of North America National Conference*, 2015.

[99] G. Carlsson, B. Slaug, S. Schmidt, L. Norin, E. Ronchi, and G. Gefenaite, "A scoping review of public building accessibility," *Disability and Health Journal*, vol. 15, no. 2, p. 101227, 2022.

[100] W. Jeamwatthanachai, M. Wald, and G. Wills, "Building rating system: an instrument for building accessibility measurement for better indoor navigation by blind people," *Journal of Enabling Technologies*, vol. 13, no. 3, pp. 158–172, 2019.

[101] P. L. Emiliani, "Assistive technology (at) versus mainstream technology (mst): The research perspective," *Technology and Disability*, vol. 18, no. 1, pp. 19–29, 2006.

[102] A. Hurst and J. Tobias, "Empowering individuals with do-it-yourself assistive technology," in *The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility*, pp. 11–18, 2011.

[103] D. Cruz, M. L. G. Emmel, M. G. Manzini, and P. V. Braga Mendes, "Assistive technology accessibility and abandonment: challenges for occupational therapists," *The Open Journal of Occupational Therapy*, vol. 4, no. 1, p. 10, 2016.

[104] C. L. Bennett, E. Brady, and S. M. Branham, "Interdependence as a frame for assistive technology research and design," in *Proceedings of the 20th international acm sigaccess conference on computers and accessibility*, pp. 161–173, 2018.

[105] J. L. Nasar, J. Evans-Cowley, *et al.*, *Universal design and visitability: From accessibility to zoning.* Ohio State University, 2007.

[106] S. A. Kadir and M. Jamaludin, "Applicability of malaysian standards and universal design in public buildings in putrajaya," *Procedia-Social and Behavioral Sciences*, vol. 36, pp. 659–669, 2012.

[107] S. Goldsmith, *Universal design.* Routledge, 2007.

[108] R. Imrie and P. Hall, *Inclusive design: designing and developing accessible environments.* Taylor & Francis, 2003.

[109] J. P. Salmen, "Us accessibility codes and standards: challenges for universal design," 2001.

[110] A. Gossett, A. Gossett, M. Mirza, A. K. Barnds, and D. Feidt, "Beyond access: A case study on the intersection between accessibility, sustainability, and universal design," *Disability and Rehabilitation: Assistive Technology*, vol. 4, no. 6, pp. 439–450, 2009.

[111] S. Djurhuus, H. Sten Hansen, M. Aadahl, and C. Glümer, "Building a multimodal network and determining individual accessibility by public transportation," *Environment and Planning B: Planning and Design*, vol. 43, no. 1, pp. 210–227, 2016.

[112] P. Demian and D. Walters, "The advantages of information management through building information modelling," *Construction management and economics*, vol. 32, no. 12, pp. 1153–1165, 2014.

[113] K. Harji and E. T. Jackson, "Facing challenges, building the field: Improving the measurement of the social impact of market-based approaches," *American Journal of Evaluation*, vol. 39, no. 3, pp. 396–401, 2018.

[114] A. Habib, V. R. Prybutok, and D. Philpot, "Assessing and building municipal open data capability," *Information Systems and e-Business Management*, pp. 1–25, 2022.

[115] Y.-H. Cheng and S.-Y. Chen, "Perceived accessibility, mobility, and connectivity of public transportation systems," *Transportation Research Part A: Policy and Practice*, vol. 77, pp. 386–403, 2015.

[116] L. F. Cunningham, C. E. Young, and M. Lee, "Developing customer-based measures of overall transportation service quality in colorado: Quantitative and qualitative approaches," *Journal of Public Transportation*, vol. 1, no. 4, pp. 1–21, 1996.

[117] M.-H. Shin, J.-H. Jung, and H.-Y. Kim, "Quantitative and qualitative analysis of applying building information modeling (bim) for infrastructure design process," *Buildings*, vol. 12, no. 9, p. 1476, 2022.

[118] J. J. Wesley, "Building bridges in content analysis: quantitative and qualitative traditions," in *Annual meeting of the Canadian Political Science Association. Carleton University, Ottawa, May*, vol. 29, 2009.

[119] K. Martens and A. Golub, "Accessibility measures and equity: A philosophical exploration," in *Transportation Research Board 91st Annual Meeting*, 2012.

[120] A. R. Maroko, J. A. Maantay, N. L. Sohler, K. L. Grady, and P. S. Arno, "The complexities of measuring access to parks and physical activity sites in new york city: a quantitative and qualitative approach," *International journal of health geographics*, vol. 8, no. 1, pp. 1–23, 2009.

[121] K. T. Geurs and B. Van Wee, "Accessibility evaluation of land-use and transport strategies: review and research directions," *Journal of Transport geography*, vol. 12, no. 2, pp. 127–140, 2004.

[122] K. T. Geurs, K. J. Krizek, and A. Reggiani, *Accessibility analysis and transport planning: challenges for Europe and North America.* Edward Elgar Publishing, 2012.

[123] D. Halden, D. Mcguigan, A. Nisbet, and A. Mckinnon, *Accessibility: Review of measuring techniques and their application.* Great Britain, Scottish Executive, Central Research Unit Edinburgh, UK, 2000.

[124] G. H. Pirie, "Measuring accessibility: a review and proposal," *Environment and planning A*, vol. 11, no. 3, pp. 299–312, 1979.

[125] B. Van Wee, M. Hagoort, and J. A. Annema, "Accessibility measures with competition," *Journal of Transport geography*, vol. 9, no. 3, pp. 199–208, 2001.

[126] B. Van Wee and K. Geurs, "Discussing equity and social exclusion in accessibility evaluations," *European journal of transport and infrastructure research*, vol. 11, no. 4, 2011.

[127] B. Van Wee, "Accessible accessibility research challenges," *Journal of transport geography*, vol. 51, pp. 9–16, 2016.

[128] A. Malekzadeh and E. Chung, "A review of transit accessibility models: Challenges in developing transit accessibility models," *International journal of sustainable transportation*, vol. 14, no. 10, pp. 733–748, 2020.

[129] M. Kulkarni, "Digital accessibility: Challenges and opportunities," *IIMB Management Review*, vol. 31, no. 1, pp. 91–98, 2019.

[130] A. Ramírez-Vega, F. Iniesto, and C. Rodrigo, "Raising awareness of the accessibility challenges in mathematics moocs," in *Proceedings of the 5th International Conference on Technological Ecosystems for Enhancing Multiculturality*, pp. 1–8, 2017.

[131] S. Geissler, A. G. Charalambides, and M. Hanratty, "Public access to building related energy data for better decision making in implementing energy efficiency strategies: Legal barriers and technical challenges," *Energies*, vol. 12, no. 10, p. 2029, 2019.

[132] L. Goldberg, B. Lide, S. Lowry, H. A. Massett, T. O'Connell, J. Preece, W. Quesenbery, and B. Shneiderman, "Usability and accessibility in consumer health informatics: current trends and future challenges," *American journal of preventive medicine*, vol. 40, no. 5, pp. S187–S197, 2011.

[133] G. Pisoni, N. Díaz-Rodríguez, H. Gijlers, and L. Tonolli, "Human-centered artificial intelligence for designing accessible cultural heritage," *Applied Sciences*, vol. 11, no. 2, p. 870, 2021.

[134] R. S. Olson, M. Sipper, W. L. Cava, S. Tartarone, S. Vitale, W. Fu, P. Orzechowski, R. J. Urbanowicz, J. H. Holmes, and J. H. Moore, "A system for accessible artificial intelligence," in *Genetic programming theory and practice XV*, pp. 121–134, Springer, 2018.

[135] D. Tsay and C. Patterson, "From machine learning to artificial intelligence applications in cardiac care: real-world examples in improving imaging and patient access," *Circulation*, vol. 138, no. 22, pp. 2569–2575, 2018.

[136] S. Abou-Zahra, J. Brewer, and M. Cooper, "Artificial intelligence (ai) for web accessibility: Is conformance evaluation a way forward?," in *Proceedings of the 15th International Web for All Conference*, pp. 1–4, 2018.

[137] A. M. Hopkins, J. M. Logan, G. Kichenadasse, and M. J. Sorich, "Artificial intelligence chatbots will revolutionize how cancer patients access information: Chatgpt represents a paradigm-shift," *JNCI Cancer Spectrum*, vol. 7, no. 2, p. pkad010, 2023.

[138] O. Diaz, K. Kushibar, R. Osuala, A. Linardos, L. Garrucho, L. Igual, P. Radeva, F. Prior, P. Gkontra, and K. Lekadir, "Data preparation for artificial intelligence in medical imaging: A comprehensive guide to open-access platforms and tools," *Physica medica*, vol. 83, pp. 25–37, 2021.

[139] D. G. Lowe, "Three-dimensional object recognition from single two-dimensional images," *Artificial intelligence*, vol. 31, no. 3, pp. 355–395, 1987.

[140] A. Jain, R. Ramaprasad, P. Narang, M. Mandal, V. Chamola, F. R. Yu, and M. Guizan, "Ai-enabled object detection in uavs: challenges, design choices, and research directions," *IEEE Network*, vol. 35, no. 4, pp. 129–135, 2021.

[141] S. A. Nawaz, J. Li, U. A. Bhatti, M. U. Shoukat, and R. M. Ahmad, "Ai-based object detection latest trends in remote sensing, multimedia and agriculture applications," *Frontiers in Plant Science*, vol. 13, p. 1041514, 2022.

[142] S. Benjamens, P. Dhunnoo, and B. Meskó, "The state of artificial intelligence-based fda-approved medical devices and algorithms: an online database," *NPJ digital medicine*, vol. 3, no. 1, p. 118, 2020.

[143] W. Tong, H. Hong, H. Fang, Q. Xie, and R. Perkins, "Decision forest: combining the predictions of multiple independent decision tree models," *Journal of Chemical Information and Computer Sciences*, vol. 43, no. 2, pp. 525–531, 2003.

[144] Y.-Y. Song and L. Ying, "Decision tree methods: applications for classification and prediction," *Shanghai archives of psychiatry*, vol. 27, no. 2, p. 130, 2015.

[145] E. G. Petre, "A decision tree for weather prediction," *Bul. Univ. Pet.–Gaze din Ploieşti*, vol. 61, no. 1, pp. 77–82, 2009.

[146] T. Amraee and S. Ranjbar, "Transient instability prediction using decision tree technique," *IEEE Transactions on power systems*, vol. 28, no. 3, pp. 3028–3037, 2013.

[147] L. Breiman, "Random forests," *Machine learning*, vol. 45, pp. 5–32, 2001.

[148] Y. Liu, Y. Wang, and J. Zhang, "New machine learning algorithm: Random forest," in *Information Computing and Applications: Third International Conference, ICICA 2012, Chengde, China, September 14-16, 2012. Proceedings 3*, pp. 246–252, Springer, 2012.

[149] A. Cutler, D. R. Cutler, and J. R. Stevens, "Random forests," *Ensemble machine learning: Methods and applications*, pp. 157–175, 2012.

[150] M. Segal and Y. Xiao, "Multivariate random forests," *Wiley interdisciplinary reviews: Data mining and knowledge discovery*, vol. 1, no. 1, pp. 80–87, 2011.

[151] N. Zimmerman, A. A. Presto, S. P. Kumar, J. Gu, A. Hauryliuk, E. S. Robinson, A. L. Robinson, and R. Subramanian, "A machine learning calibration model using random forests to improve sensor performance for lower-cost air quality monitoring," *Atmospheric Measurement Techniques*, vol. 11, no. 1, pp. 291–313, 2018.

[152] D. Maulud and A. M. Abdulazeez, "A review on linear regression comprehensive in machine learning," *Journal of Applied Science and Technology Trends*, vol. 1, no. 4, pp. 140–147, 2020.

[153] S. Rong and Z. Bao-Wen, "The research of regression model in machine learning field," in *MATEC Web of Conferences*, vol. 176, p. 01033, EDP Sciences, 2018.

[154] S. Kavitha, S. Varuna, and R. Ramya, "A comparative analysis on linear regression and support vector regression," in *2016 online international conference on green engineering and technologies (IC-GET)*, pp. 1–5, IEEE, 2016.

[155] E. Jumin, N. Zaini, A. N. Ahmed, S. Abdullah, M. Ismail, M. Sherif, A. Sefelnasr, and A. El-Shafie, "Machine learning versus linear regression modelling approach for accurate ozone concentrations prediction," *Engineering Applications of Computational Fluid Mechanics*, vol. 14, no. 1, pp. 713–725, 2020.

[156] T. M. Hope, "Linear regression," in *Machine Learning*, pp. 67–81, Elsevier, 2020.

[157] D. Liang, D. A. Frederick, E. E. Lledo, N. Rosenfield, V. Berardi, E. Linstead, and U. Maoz, "Examining the utility of nonlinear machine learning approaches versus linear regression for predicting body image outcomes: The us body project i," *Body Image*, vol. 41, pp. 32–45, 2022.

[158] T. Fischer and C. Krauss, "Deep learning with long short-term memory networks for financial market predictions," *European journal of operational research*, vol. 270, no. 2, pp. 654–669, 2018.

[159] C. Hu, Q. Wu, H. Li, S. Jian, N. Li, and Z. Lou, "Deep learning with a long short-term memory networks approach for rainfall-runoff simulation," *Water*, vol. 10, no. 11, p. 1543, 2018.

[160] J. Brownlee, *Long short-term memory networks with python: develop sequence prediction models with deep learning*. Machine Learning Mastery, 2017.

[161] S. Punia, K. Nikolopoulos, S. P. Singh, J. K. Madaan, and K. Litsiou, "Deep learning with long short-term memory networks and random forests for demand forecasting in multi-channel retail," *International journal of production research*, vol. 58, no. 16, pp. 4964–4979, 2020.

[162] W. Li, N. Sengupta, P. Dechent, D. Howey, A. Annaswamy, and D. U. Sauer, "Online capacity estimation of lithium-ion batteries with deep long short-term memory networks," *Journal of power sources*, vol. 482, p. 228863, 2021.

[163] R. Zhang, Z. Chen, S. Chen, J. Zheng, O. Büyüköztürk, and H. Sun, "Deep long short-term memory networks for nonlinear structural seismic response prediction," *Computers & Structures*, vol. 220, pp. 55–68, 2019.

[164] D. Cozzolino, "The sample, the spectra and the maths—the critical pillars in the development of robust and sound applications of vibrational spectroscopy," *Molecules*, vol. 25, no. 16, p. 3674, 2020.

[165] W. Chen, L. Yang, B. Zha, M. Zhang, and Y. Chen, "Deep learning reservoir porosity prediction based on multilayer long short-term memory network," *Geophysics*, vol. 85, no. 4, pp. WA213–WA225, 2020.

[166] R. Gajanayake, R. Iannella, and T. Sahama, "Privacy oriented access control for electronic health records," *Electronic Journal of Health Informatics*, vol. 8, no. 2, pp. Article–number, 2014.

[167] R. O. Smith, "Measuring the outcomes of assistive technology: Challenge and innovation," *Assistive technology*, vol. 8, no. 2, pp. 71–81, 1996.

[168] D. Williams, N. Johnson, A. K. Saha, N. Spaeth, D. Tomashek, S. I. Ahamed, and R. O. Smith, "Access ruler: An accessible measurement application for determining accessibility in the built environment," in *2016 Rehabilitation Engineering and Assistive Society of North America National Conference*, 2016.

[169] Q. M. Obiedat, J. Schwartz, R. Mendonca, S. Burns, M. Drake, L. O'Donnell, and R. O. Smith, "Using video recordings as a covid-19 adaptation to study the interrater reliability of the accesstools app," 2021.

[170] E. Anderson, R. Smith, and M. Hammick, "Evaluating an interprofessional education curriculum: a theory-informed approach," *Medical teacher*, vol. 38, no. 4, pp. 385–394, 2016.

[171] T. K. Tegegne, C. Chojenta, T. Getachew, R. Smith, and D. Loxton, "Antenatal care use in ethiopia: a spatial and multilevel analysis," *BMC pregnancy and childbirth*, vol. 19, pp. 1–16, 2019.

[172] Q. M. Obiedat, J. K. Schwartz, R. Mendonca, S. Burns, R. O. Smith, and L. O'Donnell, "Studying the educational effect of a self-paced learning protocol for evaluating community environment accessibility: A preliminary analysis.," *American Journal of Occupational Therapy*, vol. 76, 2022.

[173] F. Xu, H. Uszkoreit, Y. Du, W. Fan, D. Zhao, and J. Zhu, "Explainable ai: A brief survey on history, research areas, approaches and challenges," in *Natural Language Processing and Chinese Computing: 8th CCF International Conference, NLPCC 2019, Dunhuang, China, October 9–14, 2019, Proceedings, Part II 8*, pp. 563–574, Springer, 2019.

[174] D. Gunning, M. Stefik, J. Choi, T. Miller, S. Stumpf, and G.-Z. Yang, "Xai—explainable artificial intelligence," *Science robotics*, vol. 4, no. 37, p. eaay7120, 2019.

[175] K. Gade, S. C. Geyik, K. Kenthapadi, V. Mithal, and A. Taly, "Explainable ai in industry," in *Proceedings of the 25th ACM SIGKDD international conference on knowledge discovery & data mining*, pp. 3203–3204, 2019.

[176] D. Doran, S. Schulz, and T. R. Besold, "What does explainable ai really mean? a new conceptualization of perspectives," *arXiv preprint arXiv:1710.00794*, 2017.

[177] W. Samek, G. Montavon, A. Vedaldi, L. K. Hansen, and K.-R. Müller, *Explainable AI: interpreting, explaining and visualizing deep learning*, vol. 11700. Springer Nature, 2019.

[178] C. M. Nishita, P. S. Liebig, J. Pynoos, L. Perelman, and K. Spegal, "Promoting basic accessibility in the home: Analyzing patterns in the diffusion of visitability legislation," *Journal of Disability Policy Studies*, vol. 18, no. 1, pp. 2–13, 2007.

[179] A. Olalere and J. Lazar, "Accessibility of us federal government home pages: Section 508 compliance and site accessibility statements," *Government Information Quarterly*, vol. 28, no. 3, pp. 303–309, 2011.

[180] S. M. Branham and S. K. Kane, "Collaborative accessibility: How blind and sighted companions co-create accessible home spaces," in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pp. 2373–2382, 2015.

[181] D. A. Brent, J. A. Perper, C. J. Allman, G. M. Moritz, M. E. Wartella, and J. P. Zelenak, "The presence and accessibility of firearms in the homes of adolescent suicides: a case-control study," *Jama*, vol. 266, no. 21, pp. 2989–2995, 1991.

[182] C. M. Guy, "The assessment of access to local shopping opportunities: a comparison of accessibility measures," *Environment and planning b: Planning and design*, vol. 10, no. 2, pp. 219–237, 1983.

[183] D. M. Levinson, "Accessibility and the journey to work," *Journal of transport geography*, vol. 6, no. 1, pp. 11–21, 1998.

[184] G. La Cava, H. Leal, A. Zurawski, *et al.*, "Housing accessibility for first home buyers| bulletin–december 2017," 2017.

[185] C. Weinberg and O. Nwosu, "Home-making," *Thinking Home: Interdisciplinary Dialogues*, 2020.

[186] P. Webb, J. Coates, E. A. Frongillo, B. L. Rogers, A. Swindale, and P. Bilinsky, "Measuring household food insecurity: why it's so important and yet so difficult to do," *The Journal of nutrition*, vol. 136, no. 5, pp. 1404S–1408S, 2006.

[187] M. J. Moseley, *Accessibility: the rural challenge*. Taylor & Francis, 2023.

[188] M. Q. Dalvi and K. Martin, "The measurement of accessibility: some preliminary results," *Transportation*, vol. 5, no. 1, pp. 17–42, 1976.

[189] E. J. Miller, "Accessibility: measurement and application in transportation planning," *Transport Reviews*, vol. 38, no. 5, pp. 551–555, 2018.

[190] V. I. Ogu and J. E. Ogbuozobe, "Housing policy in nigeria: towards enablement of private housing development," *Habitat international*, vol. 25, no. 4, pp. 473–492, 2001.

[191] C. Liu and Q. Shen, "An empirical analysis of the influence of urban form on household travel and energy consumption," *Computers, Environment and Urban Systems*, vol. 35, no. 5, pp. 347–357, 2011.

[192] B. Giles-Corti, M. H. Broomhall, M. Knuiman, C. Collins, K. Douglas, K. Ng, A. Lange, and R. J. Donovan, "Increasing walking: how important is distance to, attractiveness, and size of public open space?," *American journal of preventive medicine*, vol. 28, no. 2, pp. 169–176, 2005.

[193] H. Touqeer, S. Zaman, R. Amin, M. Hussain, F. Al-Turjman, and M. Bilal, "Smart home security: challenges, issues and solutions at different iot layers," *The Journal of Supercomputing*, vol. 77, no. 12, pp. 14053–14089, 2021.

[194] H. J. Miller, "Place-based versus people-based accessibility," in *Access to destinations*, pp. 63–89, Emerald Group Publishing Limited, 2005.

[195] E. Báscolo, N. Houghton, and A. Del Riego, "Leveraging household survey data to measure barriers to health services access in the americas," *Revista Panamericana de Salud Pública*, vol. 44, 2020.

[196] J. Chen, K. de Hoogh, J. Gulliver, B. Hoffmann, O. Hertel, M. Ketzel, M. Bauwelinck, A. Van Donkelaar, U. A. Hvidtfeldt, K. Katsouyanni, *et al.*, "A comparison of linear regression, regularization, and machine learning algorithms to develop europe-wide spatial models of fine particles and nitrogen dioxide," *Environment international*, vol. 130, p. 104934, 2019.

[197] J. Bugeja, A. Jacobsson, and P. Davidsson, "On privacy and security challenges in smart connected homes," in *2016 European Intelligence and Security Informatics Conference (EISIC)*, pp. 172–175, IEEE, 2016.

[198] K. Li, V. G. Duffy, and L. Zheng, "Universal accessibility assessments through virtual interactive design," *International Journal of Human Factors Modelling and Simulation*, vol. 1, no. 1, pp. 52–68, 2006.

[199] I. Munoko, H. L. Brown-Liburd, and M. Vasarhelyi, "The ethical implications of using artificial intelligence in auditing," *Journal of Business Ethics*, vol. 167, pp. 209–234, 2020.

[200] N. T. Tippins, F. L. Oswald, and S. M. McPhail, "Scientific, legal, and ethical concerns about ai-based personnel selection tools: a call to action," *Personnel Assessment and Decisions*, vol. 7, no. 2, p. 1, 2021.

[201] A. A. Kodiyan, "An overview of ethical issues in using ai systems in hiring with a case study of amazon's ai based hiring tool," *Researchgate Preprint*, pp. 1–19, 2019.

[202] M. Whittaker, K. Crawford, R. Dobbe, G. Fried, E. Kaziunas, V. Mathur, S. M. West, R. Richardson, J. Schultz, O. Schwartz, *et al.*, *AI now report 2018*. AI Now Institute at New York University New York, 2018.

[203] M. Wei and Z. Zhou, "Ai ethics issues in real world: Evidence from ai incident database," *arXiv preprint arXiv:2206.07635*, 2022.

[204] P. Esmaeilzadeh, "Use of ai-based tools for healthcare purposes: a survey study from consumers' perspectives," *BMC medical informatics and decision making*, vol. 20, no. 1, pp. 1–19, 2020.