Design Guidelines of an Inclusive Fully Autonomous Vehicle System and Interactions for Older People

by

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Abstract

The aging population is a significant global challenge. As the older population continues to grow, mobility issues faced by older adults are exacerbated by physical and cognitive difficulties associated with aging. Fully Autonomous Vehicles (FAVs) are proposed as a potential solution to address these mobility challenges and offer enhanced accessibility and independence to older people. However, current FAV research often lacks sufficient focus on effectively engaging older people, fostering their familiarity and trust with new technologies, and ensuring their comfort when using FAVs. These shortcomings highlight the need for an accessible, user-friendly design approach tailored to older people who wish to use FAVs.

This study aims to develop design guidelines for future inclusive FAV transportation, utilizing intuitive and affordance-based UX/UI design principles and services that consider the specific characteristics and needs of older users. Furthermore, these guidelines will serve as a foundation for developing inclusive FAV design tools, assisting designers in creating accessible transportation solutions, and providing essential data for future development of FAVs tailored for older people. To ensure the research's robustness, this thesis will incorporate various design principles and supporting case studies.

Artificial Intelligence (AI) Use Disclosure Statement

In the preparation of this thesis, the Artificial Intelligence (AI) tool **Gemini (developed by Google)** was used. This tool was utilized primarily to assist with English proofreading, enhance grammatical clarity, and suggest vocabulary improvements throughout the drafting process. The author acknowledges full responsibility for the intellectual content of this work and has ensured that all AI-assisted sections have been thoroughly reviewed and revised to maintain academic integrity and accuracy.

Digital Accessibility Disclosure Statement

In the preparation of this thesis, the following digital accessibility tools were used to ensure this document complies with federal requirements: MS Word's built-in accessibility checker and Adobe Acrobat Pro. The author acknowledges full responsibility for the intellectual content of this work and has made a good faith effort to comply with digital accessibility requirements in publishing, wherein the nature of the content does not significantly change in order to do so. Furthermore, all content has been reviewed and revised to meet these requirements prior to final publication.

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Chapter 1 Introduction

1.1 Problem Statement

American society faces a fundamental demographic shift. By 2034, the number of people aged 65 and older is projected to surpass the number of children under 18 for the first time in American history. For this demographic, mobility is essential to maintaining physical and mental health and to engaging in active social participation. However, many older adults encounter difficulties in driving or cease driving altogether due to declines in physical and cognitive functions, which act as a significant barrier to their mobility. According to the Surface Transportation Policy Project (STPP), 20 percent of adults aged 65 and older do not drive and experience increased stress in traffic situations. This trend is gradually intensifying, and the older population aged 65 and older in the United States is projected to exceed 72 million by 2030 (Nash, A., 2019; WHO, 2025).

This demographic shift is leading to a significant number of older adults ceasing to drive due to age-related physical and cognitive decline, severely limiting their access to essential services, healthcare, and social interactions. Consequently, these mobility limitations lead to social isolation and a reduced quality of life (Webber, Porter, & Menec, 2010). Existing public transportation systems that older people rely on to move also present several challenges for them, including low accessibility, relatively high costs, and difficulty of use due to complex systems and procedures. These mobility limitations can ultimately lead to social isolation, a reduced quality of life, and health problems for older people (Zhang & Yang, 2024).

1.2 Need for Study

Research by Zandieh and Acheampong (2021), in their article "Mobility and Healthy Aging in the City," has shown that older adults experience significant mobility challenges in their daily lives. Many older people need to travel frequently, more than four times a week, for essential activities such as grocery shopping, socializing, and attending medical appointments. However, age-related physical and cognitive impairments significantly limit their mobility and accessibility, resulting in frustration, isolation, and a deterioration in overall health and well-being (Webber et al., 2010).

Unfortunately, current public transportation systems present numerous barriers, including inadequate infrastructure, complex usage procedures, and limited accessibility that is not necessarily tailored to older people’s specific needs. These existing challenges will only intensify as the aging population continues to grow, outpacing the development of suitable transportation infrastructure and services. Current Fully Autonomous Vehicle (FAV) designs have largely overlooked the unique needs of older adults, despite FAVs showing potential to enhance older adults' independence by offering simplified use and improved accessibility. Moreover, while technological advancements have enabled the development of autonomous vehicles, the design of FAVs that specifically address the accessibility needs of older adults remains underdeveloped. This neglect creates significant barriers for older individuals when learning to use and adapt to autonomous transportation technologies (Meyer et al., 2017).

Given these circumstances, there is an evident need for research focused on developing inclusive design guidelines and user-friendly UX/UI for FAV users. Such design tools will provide designers with practical strategies to enhance trust, usability, and active participation among older passengers.

Therefore, the need for this study goes beyond simply proposing a new FAVs design. It aims to bridge the gap between theory and incomplete practice practically. By synthesizing and reinterpreting existing design principles, this study aims to provide specific, actionable guidelines that help designers comprehensively understand the physical, cognitive, and emotional needs of older adults and incorporate them into actual FAV designs.

Ultimately, this study will provide fundamental knowledge and practical solutions for the development of future FAV systems and comprehensive guidelines for their design, thereby helping older adults maintain mobility, autonomy, and overall quality of life.

1.3 Objectives of the Study

The ultimate objective of this study is to develop a design guideline framework for the system and interaction of inclusive FAVs for people. This framework aims to help designers and engineers systematically address the trust, usability, and safety challenges older adults face when interacting with new technologies. Another key goal of this design guideline is to make FAVs easily accessible and user-friendly for a diverse range of older users by prioritizing both usability and inclusive accessibility.

Therefore, the core challenge addressed by this study is not simply engineering accessible vehicles but designing and trust-building 'experiences' that bridge the gap between the potential of technology and the nuanced and complex human needs of older adults.

- To achieve this primary objective, this study sets the following specific objectives:
- To develop a comprehensive design guideline framework for Fully Autonomous Vehicles (FAVs) that systematically addresses the safety, accessibility, and usability challenges faced by older users.
- To analyze the mobility limitations of older users and critically evaluate existing FAVs through case studies to identify current design gaps and opportunities for inclusivity.
- To apply the proposed guidelines to the redesign of an existing FAV model (e.g., Zoox), demonstrating practical improvements in interior space, user interaction, and visual interface for older passengers.
- To contribute to a more inclusive mobility future by providing designers and engineers with an actionable framework that fosters trust and encourages the adoption of autonomous technology among the aging population.

1.4 Definition of Terms

Accessibility: Accessibility is the design of products, devices, services, or environments for people with disabilities or impairments (W3C, n.d.).

Americans with Disabilities Act (ADA): The ADA is a law enacted in 1990 that prevents discrimination against individuals with disabilities and guarantees equal access and opportunities in public facilities, employment, transportation, and more (ADA National Network, n.d.).

Anthropometry: The science of defining physical measurements of an individual's body size, shape, and functional capacities. Anthropometry is widely applied in design, ergonomics, and healthcare fields to optimize human-use products and environments (Pheasant & Haslegrave, 2006).

Anthropomorphism: The act of portraying animals, gods, and objects as if they have human-like appearance, personality, or behavior (Cambridge Dictionary, n.d.).

Ageism: Ageism involves stereotypes, prejudice, and discrimination directed at others or oneself due to age (WHO, 2025).

CDC: Centers for Disease Control and Prevention, the United States' primary science-based, data-driven public health organization. The CDC aims to protect and improve public health through research, data collection, and health services (CDC, n.d.).

Ergonomics: Ergonomics examines how people do their work, considering the worker, their methods, tools, environment, and relevant psychological and social aspects (Pheasant & Haslegrave, 2006).

FAV: Abbreviation for *Fully Autonomous Vehicle*, referring to a vehicle that can drive itself without human intervention (National Highway Traffic Safety Administration, n.d.).

Heuristic: An experiential or intuitive approach to problem-solving that enables individuals or systems to solve problems efficiently. Heuristics do not necessarily provide optimal solutions but are useful for finding practical, timely solutions (Merriam-Webster, n.d.).

HCD: Human-centered design is an approach to design that prioritizes the users' needs, preferences, and limitations at every step of the process (Interaction Design Foundation, 2021).

Mobility as a Service (MaaS): MaaS combines different transportation modes and related services into one unified, on-demand mobility platform. It provides users with the convenience of using a single app and payment method, replacing the need for multiple tickets and payment systems (MaaS Alliance, n.d.).

Stigmatization: Stigmatization is the social process of devaluing, labeling, and marginalizing individuals or groups based on perceived negative traits, such as mental illness, poverty, or race. It involves stereotypes, prejudice, and discrimination that lead to exclusion and reduced life chances. Effects include intense psychological distress, isolation, and avoidance of help-seeking, while reinforcing inequality and hindering social cohesion (Jena University Hospital, n.d.).

UX: User Experience (UX) refers to the overall experience a user has when interacting with a product or service, including factors like usability, functionality, and satisfaction (NN/g, n.d.).

UI: User Interface (UI) refers to the interface through which users interact with a system, including visual design elements such as buttons, icons, and layouts (Interaction Design Foundation, 2016).

1.5 Assumptions

- It is assumed that all references and research data are accurate and valid.

- It is assumed that Level 5 FAV will be commercialized within the next 10 years.
- This study assumes that Inclusive FAV taxis can solve mobility and accessibility issues faced by older people.
- It is assumed that this guideline will contribute to Inclusive FAV development and interactions with older people.
- This study assumes that the guideline will increase older users' engagement with Inclusive FAV taxis and help them quickly adapt to new features.

1.6 Scope and Limitations

Scope

- Inclusive FAVs are accessible to all users, but this study primarily focuses on older individuals aged 65 to 85 who experience mobility and accessibility challenges in daily life.
- This study focuses on the interior, interactions, and interface design of Inclusive FAV taxis.
- This study also explores the integration of advanced safety features in the design of an Inclusive FAV taxi to ensure the comfort and security of older passengers.

Limits

- While there are various types of autonomous vehicles, this study focuses exclusively on Inclusive FAVs.
- This study does not address the development of autonomous vehicles.
- Although FAVs can cover a wide range of travel, the Inclusive FAV taxi in this study is limited to operating within town boundaries, given the typical range of movement for older people.

1.7 Procedure and Methodology

Procedure 1. Identifying challenges and issues that older people face in public transportation through research and literature review.

- Research various sources to understand the difficulties older people encounter and their impact.
- Analyze the current transportation limitations and develop the foundational concepts for Inclusive FAVs.

Procedure 2. Investigating existing inclusive and autonomous vehicles to find successful and unsuccessful examples of functionalities and addressing of needs.

- Conduct a case study to identify the essential features that FAVs should support for older users, and analyze the differences in needs and preferences between older people and general users to determine functional requirements.

Procedure 3. Studying human ergonomics and considering inclusive design principles for vehicle interiors.

- Research optimal seating, access, and visibility based on the physical factors and limitations of older people.

Procedure 4. Researching interactions, UX/UI, and services to improve older people's engagement with FAVs.

- Apply design principles such as familiarity, intuitiveness, and simplicity to make Human-Machine interaction more visible and usable.
- Incorporate design elements that leverage familiarity with traditional transportation features to ease adoption and build user confidence.

Procedure 5. Providing design guidelines based on research to design inclusive FAVs for older people.

1.8 Anticipated Outcome

This research aims to provide inclusive UX/UI design guidelines that enable a diverse range of users to easily access future FAVs. This will be achieved through intuitive, familiar interaction design methods that encourage user adoption of this new technology. The guidelines will offer insights into usability challenges specifically faced by older users, addressing areas such as safety enhancement, accessibility, and interior design. Furthermore, they will provide concrete recommendations for UX/UI improvements designed to foster increased engagement and build trust between older users and FAVs. Expected findings include a comprehensive understanding of the common issues older users encounter, such as physical limitations and difficulties in interacting with technological interfaces. The research also anticipates demonstrating the significant impact of accessible design on enhancing comfort, building trust, and increasing the willingness of older users to adopt FAV transportation services.

The developed design tool will serve as a practical, actionable resource for automotive designers, UX/UI developers, and engineers. It will facilitate the creation of FAV interfaces that are not only compliant with accessibility standards but also truly empathetic to the older user experience. This practical guidance can potentially reduce development costs associated with iterative design processes and post-launch user dissatisfaction, thereby accelerating the market adoption of FAVs among older demographics.

In the long term, insights from this study are expected to contribute to the goal of significantly enhancing the independence and quality of life for older users by improving their mobility and accessibility. It is also expected to help older people rapidly develop trust and familiarity with previously unused technologies, thereby increasing their engagement with new products. Moreover, the comprehensive findings and the developed design tool will establish a baseline for future research on accessible autonomous mobility. This includes creating opportunities for studies on long-term user adaptation, developing highly personalized FAV interfaces, and seamlessly integrating FAVs into broader smart city infrastructure.

Chapter 2 Literature Review

2.1 Fully Autonomous Vehicle

A Fully Autonomous Vehicle (FAV) is a Level 5 fully automated driving system that can operate in all weather conditions and across all areas without a human driver (Reda et al., 2024). FAVs do not have steering wheels or acceleration/braking pedals. They will be free from geofencing, able to go anywhere and do anything an experienced human driver can. Fully autonomous cars are being tested in various parts of the world, and some are already in operation (Synopsys Editorial Staff, 2019). Research expects that more than eight million autonomous or semi-autonomous vehicles will be on the road in 2025 (ABI Research, 2018).

2.1.1 Concept of Autonomous Driving

The concept of an Autonomous Driving System (ADS) originated with Francis P. Houdina, who invented the American Wonder, which was controlled by radio waves from a following car (Hadden, 1925).

The ADS level is divided into six processes.

Level zero is "No Automation." It is fully manual, with human drivers manually controlling all functions.

Level one is "Driver Assistance." It has basic systems to assist the user, such as an Anti-Lock Braking System (ABS).

Level two is "partial automation", which provides hands-off systems such as collision avoidance and emergency braking systems to help the drivers.

Level three is "Conditional Automation". The car can drive itself, but it can only work in limited environments and still needs human control in risky situations.

Level four is similar to level three, but there is no need for human help.

Level five is "Full Automation." It means that it can operate without drivers in any situation and environment (Reda et al., 2024).

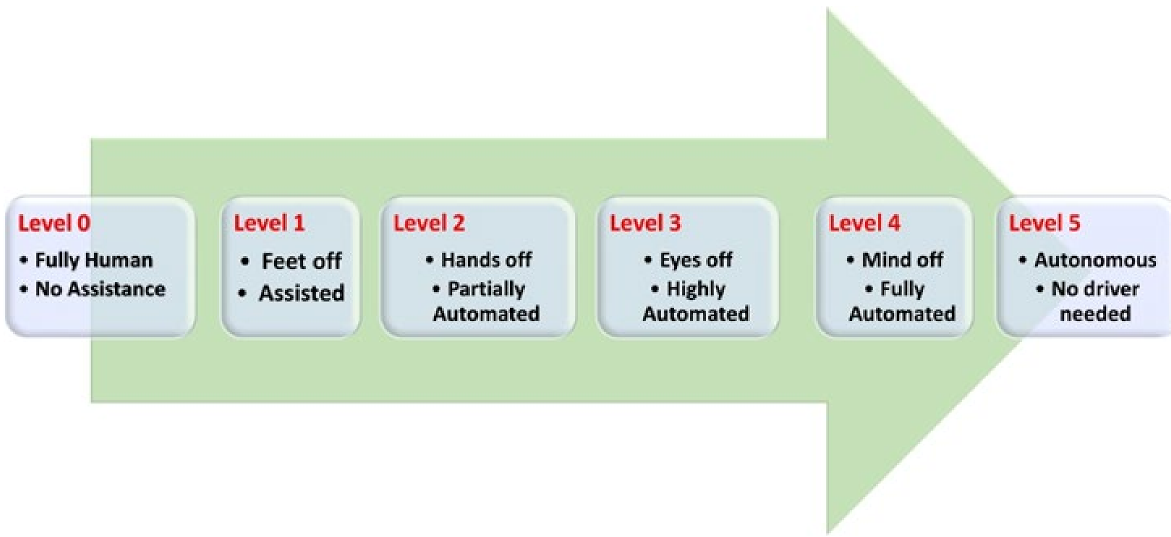


Figure 1. Level of ADS (Reda et al., 2024).

2.1.2 The Significance of FAV

While FAVs may seem like a distant possibility, autonomous technologies are rapidly advancing, with some features already integrated into current vehicle products. FAVs offer potential solutions for issues such as safety, congestion, fuel efficiency, and equity. Crucially, they can expand mobility opportunities, making car travel accessible to children and older individuals alike (Howard & Dai, 2014; Meyer et al., 2017; Tan et al., 2022). In particular, FAVs play a significant role for older people. The older population aged 65 and over is projected to continue increasing (WHO, 2025). These aging populations frequently encounter mobility challenges due to the loss of driving ability and age-related physical impairments (Webber et al., 2010). Furthermore, limited public transport network connectivity, restricted access to certain external areas, and inadequate infrastructure all contribute to mobility challenges for older adults.

The frequent travel observed among older adults (four or more times a week, both inside and outside their neighborhoods) underscores the critical importance of mobility for this demographic (refer to Fig. 2). FAVs could help older people by helping them maintain mobility, accessibility, and autonomy, thereby improving their quality of life and social inclusion. This means that physical and sensory limitations may no longer pose significant barriers to transportation use (Zandieh & Acheampong, 2021).

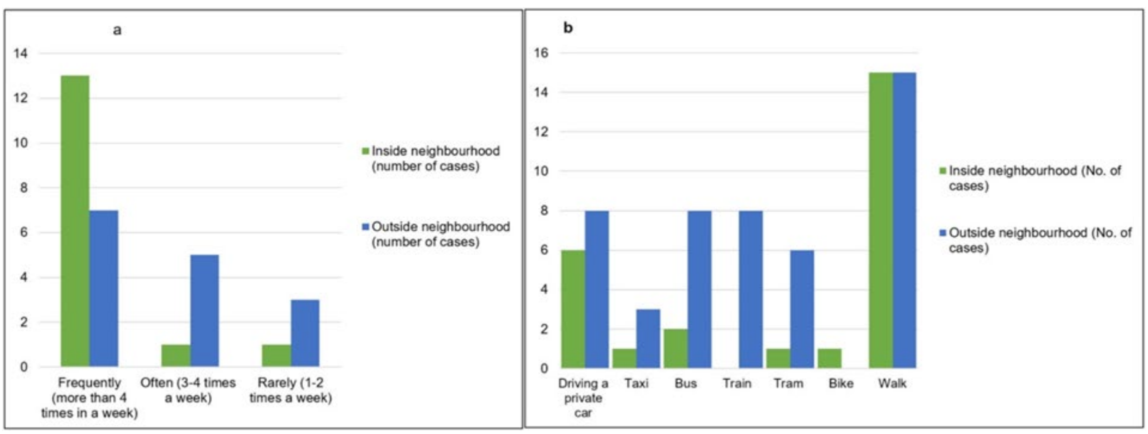


Figure 2. Male, 65 years old, driver (Zandieh & Acheampong, 2021)

2.1.3 Considerations of FAV Transportation for Older People

While FAVs offer considerable potential benefits for older users, several challenges must be addressed to encourage their adoption. A known reluctance towards new technologies may initially limit the acceptance of FAVs within this demographic (Zandieh & Acheampong, 2021). To promote engagement and widespread adoption, FAVs should be designed with user-friendly features that specifically cater to the needs and preferences of older individuals.

These design considerations include simplified and intuitive user interfaces, ergonomically designed comfortable seating, secure wheelchair locking mechanisms, and easy entry and exit mechanisms. Furthermore, integrated emergency alert systems and tailored navigation systems that prioritize accessibility will significantly enhance usability, safety, and overall user experience for older passengers (Howard & Dai, 2014; Meyer et al., 2017).

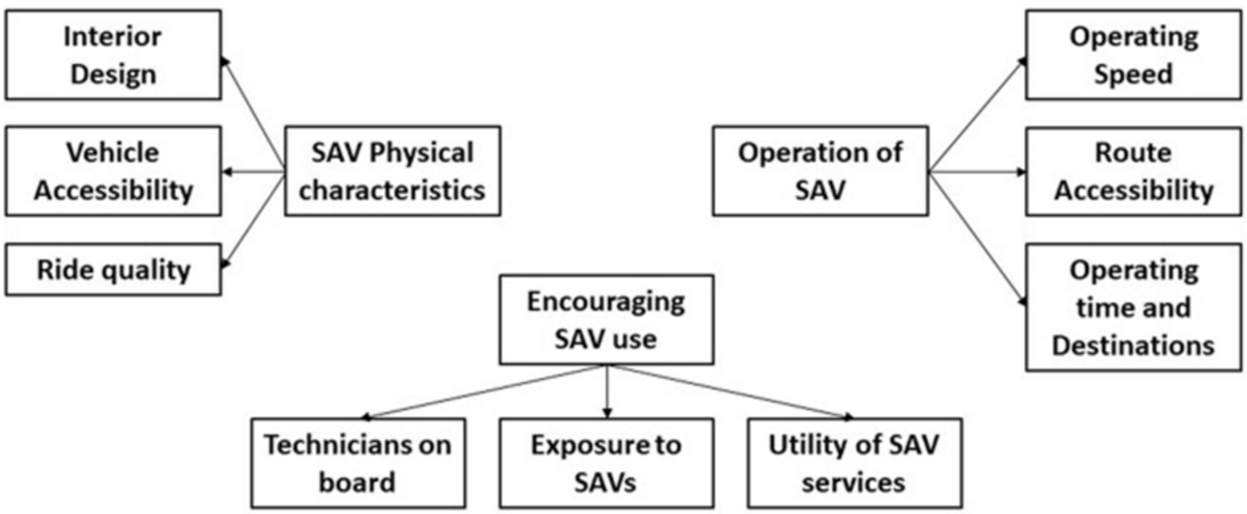


Figure 3. Map of recommendations identified by older adults (Booth et al., 2022).

2.1.3.1 Safety

Safety is one of the most important features that should be addressed in FAVs. People should entrust their safety to the autonomous driving system while riding in FAVs. They demand a higher standard of autonomous driving. The public expects FAVs to be four to five times safer than existing human-driven vehicles. If people do not perceive sufficient safety when riding in AVs, older people will not accept and adopt FAVs (Xu et al., 2018).

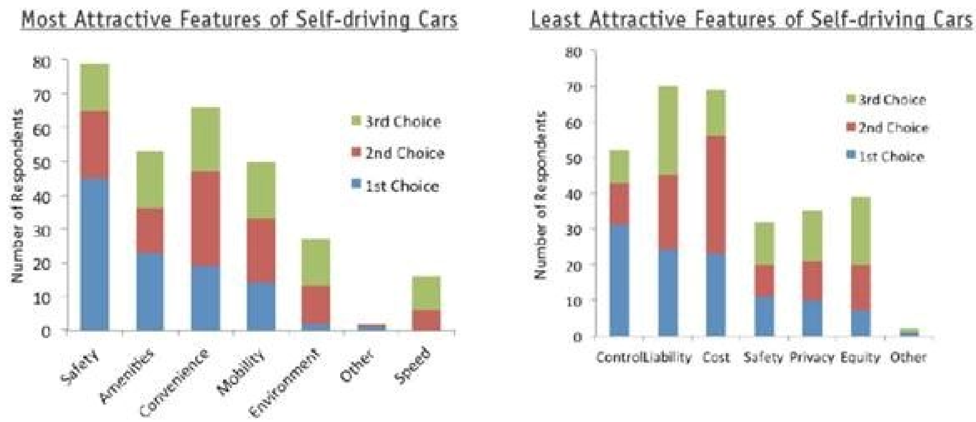


Figure 4. Most and Least Attractive Features of AV Cars (Howard & Dai, 2014).

2.1.3.2 UX/UI Tailored to Older People

User experience (UX) and user interface (UI) design are critical factors in making FAVs easy for older users to understand and operate. To design a UX/UI tailored for older users, it is necessary not only to consider the changes that occur with aging but also to understand and measure them to implement effective design solutions. These changes can be broadly categorized as physical and cognitive. Physical changes, such as declining vision and reduced motor dexterity, require UI with large fonts, high-contrast color schemes, and generously sized touch targets. Cognitive characteristics, including slower learning curves for new technologies, demand simple, consistent layouts and clear feedback for every user action (Czaja et al, 2019; National Highway Traffic Safety Administration, 2020).

The frameworks illustrated in Figures 5 and 6 provide a systematic method for this adaptation process. Their taxonomy shows that by analyzing existing products and deeply understanding the profile of older users, designers can strategically upgrade a design to be truly age-friendly. (Alhyari, & Gupta, 2022)

Figure 5. Methodology of the Proposed Taxonomy (Alhyari & Gupta, 2022).

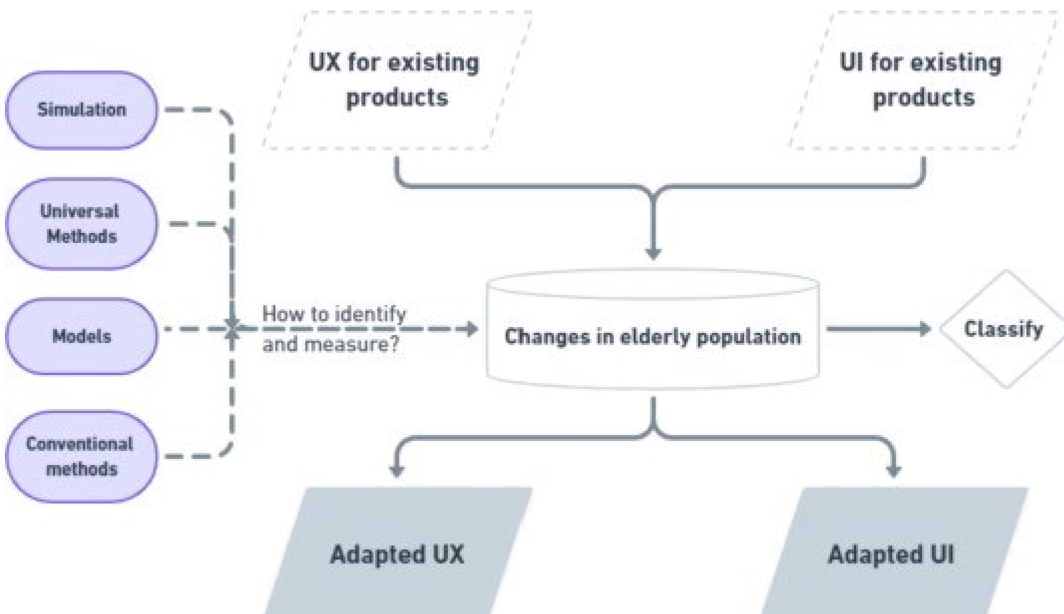


Figure 6. Taxonomy for elderly product design (Alhyari & Gupta, 2022).

2.1.3.3 Ergonomics and Anthropometry

Ergonomics was coined by the late Professor Hywel Murrell. Ergonomics is the study of work, focusing on the individuals performing it, the methods used, the tools and equipment they utilize, the environments they work in, and the psychosocial factors related to their work situation (Pheasant & Haslegrave, 2006). Ergonomics, the science of designing environments to fit the user, is crucial for ensuring FAVs are comfortable and accessible for older users, thereby increasing their acceptance and trust in the technology (Booth et al., 2022; National Highway Traffic Safety Administration, 2020). Key ergonomic considerations for an inclusive FAV interior should be based on foundational principles of accessibility design and include:

- **Vehicle Access**: Easy ingress and egress are critical. This involves designing wide-opening doors, a low vehicle floor to minimize step height, and strategically placed grab bars for support.

- **Seating Design**: Seats must provide more than just comfort; They need to offer proper support to reduce fatigue and be designed for easy entry and exit. Features such as optimal seat height, firm cushions, and adjustable lumbar support are vital.

- **Interior Layout and Storage**: Beyond passenger seating, the vehicle's interior must accommodate the realities of an older user's daily life. To get a positive response from them, it is crucial that space for personal items like shopping bags and mobility aids, such as walkers or canes, is secured and considered.

- **Ride Quality**: The vehicle's movement should be smooth and predictable. Gentle acceleration, deceleration, and turning are important ergonomic factors that prevent discomfort, motion sickness, or loss of balance for frail passengers (Booth et al., 2022).

Anthropometry is a human science focused on measuring the body's size, shape, strength, mobility, flexibility, and capacity (Pheasant & Haslegrave, 2006). This study helps designers design vehicles so that users do not need to apply or experience forces beyond acceptable or comfortable ranges. Especially when designing for older users, it is crucial to maximize comfort, safety, and accessibility by considering the physical characteristics and changes associated with aging. This includes requirements to more easily accommodate common disabilities, such as wheelchair accessibility (door/seat modifications, ramps or lifts) and changes to controls and displays (Bhise, 2024). If the physical changes and limitations of older adults are ignored, accessibility and usability can be severely degraded (Hanson, 2004).

2.1.3.4 Accessibility

According to a 2019 CDC (2019) report, over a quarter of Americans live with some form of disability, and about 12.2% struggle with walking or climbing stairs due to mobility impairments. Accessibility in FAVs refers to the design features that enable users with mobility challenges to enter, exit, and move within the vehicle independently. These features are essential not only for usability but also for ensuring equity in future transportation systems. Key design interventions include low-floor vehicle architecture, automatic or deployable ramp systems for wheelchair users, and wide door openings that facilitate easier access (Riggs & Pande, 2021).

Figure 7 further illustrates these foundational accessibility requirements, focusing on the user's entry process to show how physical design can reduce barriers and improve the experience for older or disabled passengers. (Riggs & Pande, 2021).

Feature #	Accessibility Solutions	Feature
4.3	Level Boarding	Staff manually adjusts vehicle to curb height and curb gap at stop and adjusts suspension to match if possible
4.9	Automated Ramp	Exterior Button to deploy ramp
4.10	Automated Ramp	Interior Button to deploy ramp
4.11	Automated Ramp	Steward Screen to deploy ramp
4.22	Passenger Safety	Ample lighting in the interior when boarding
4.26	Passenger Safety	Audio announce door opening
4.27	On-vehicle Validation	Vehicle opens door
4.33	Automated Ramp	Vehicle deploys ramp manually
4.51	Manual Wheelchair Restraint	Safety attendant manually assists passengers with wheelchair securement
4.57	Passenger Safety	Audio announce to wear seatbelts for all
4.63	Automated Ramp	Ramp interlocked with door position (only deploy ramp if door open)
4.64	Automated Ramp	Ramp interlocked with vehicle drive system (vehicle moves only if ramp is stowed)
4.66	Passenger Safety	Audio announce door closing
5.5	Passenger Safety	Ample lighting in the interior when riding
5.29	Remote support	Ability to store video for more than 30 days to evaluate incidents
5.32	On-vehicle Information	Audio announce next stop when vehicle starts moving at current stop
5.34	On-vehicle Information	Audio announce next stop 35 m before vehicle arrives there
5.35	On-vehicle Information	Audio announce stop when vehicle arrives there
5.42	On-vehicle Information	Audio announce in different languages
5.43	On-vehicle Information	Video display information in different languages
6.3	Level Boarding	Staff manually adjusts vehicle to curb height and curb gap at stop and adjusts suspension to match if possible
6.4	Automated Ramp	Interior button to deploy ramp
6.5	Automated Ramp	Steward screen to deploy ramp
6.9	Passenger Safety	Ample lighting in the interior when exiting
6.13	Passenger Safety	Audio announce door opening
6.14	Passenger Safety	Audio announce door closing
6.23	Automated Ramp	Vehicle deploys ramp manually
6.35	Automated Ramp	Exterior button to retract ramp
6.36	Automated Ramp	Ramp interlocked with door position (only deploy ramp if door open)
6.37	Automated Ramp	Ramp interlocked with vehicle drive system (vehicle moves only if ramp is stowed)

Figure 7. Accessibility Solutions from VTA Playbook (Riggs & Pande, 2021).

2.2 Mobility Issues in Older Users

In the FAV section, we discussed its importance for older people with mobility issues. Also, the above section explained what features older people with mobility issues need to use FAVs and why they need them. This section discusses the mobility issues they face. This discussion includes whether they have mobility issues, how these issues affect them, and what tools they currently have and need.

2.2.1 Definition of Older People

The concept of "old age" is complex, covering chronological age (based on birthdate), biological age (linked to physical health), psychological age (focused on mental and emotional well-being), and social age (related to social roles like being a grandparent) (United Nations Development Program, 2017).

- **Chronological age**: Chronological age refers to an individual’s age based on birthdate and the passage of time. The WHO (2025) defines aging as "the process of accumulation of molecular and cellular damage over time, leading to a gradual decrease in physical and mental capacity and a growing risk of disease." These biological changes vary among individuals and only loosely correlate with chronological age.
- **Biological age**: Biological age indicates a person’s functional and physiological state, which can differ from their actual chronological age. It is usually assessed using biological markers (biomarkers) that reflect physiological health. People with the same chronological age may have different biological ages, which can provide a more accurate estimate of health status and lifespan (Karasik et al., 2005).

- **Psychological age**: Psychological age refers to an individual's cognitive and emotional adaptability. According to Lumen Learning (Lally & Valentine-French, n.d.), it indicates how adaptive a person is compared to others of the same chronological age, encompassing cognitive ability, emotional stability, and one's subjective perception of age. People with higher levels of mental and physical health, cognitive function, and life satisfaction tend to perceive themselves as younger than their actual age. In contrast, those experiencing depression, cognitive decline, or stress often perceive themselves as older (Mitina et al., 2020).
- **Social age**: Social age is defined through cultural norms and social roles. It reflects how societies categorize individuals as older people based on role transitions—such as retirement, becoming a grandparent, or shifts in family and work responsibilities—or visible physical changes, including frailty and loss of capability (International Organization for Migration, 2023).

According to the United Nations (2017), individuals aged 60 and above are considered elderly, while the WHO (2025) defines the elderly as those aged 65 years and older. However, these chronological cutoffs may not fully reflect the diverse realities of aging in contemporary society. Some studies further classify individuals aged 65–74 as the early elderly and those aged 75 and above as the late elderly. In this study, the WHO's definition is adopted, defining elderly individuals as those aged 65 and above. Moreover, those within this age group who exhibit limited physical or cognitive abilities are identified as the primary elderly population for this research.

2.2.2 Understanding Disability and Mobility Impairment

Disability refers to any physical or mental condition that restricts a person’s ability to perform certain activities or engage effectively with their environment. Disabilities can impact a wide range of functional domains, including cognitive abilities (such as memory, learning, and comprehension), mobility, vision, hearing, and behavior (Laguna et al., 2024).

Among these, mobility impairments are particularly relevant when addressing transportation design for older people. Mobility limitations can result from a variety of causes, including aging, chronic diseases, and injuries. These impairments affect an individual’s ability to move independently and engage in routine physical activities, often reducing quality of life and social participation (Sükei et al., 2023).

Understanding disability and mobility impairment is essential for identifying the specific challenges faced by older individuals and other users with physical limitations. This understanding forms the foundation for designing inclusive solutions, particularly in the context of FAVs. Without accounting for such impairments, transportation systems risk excluding a significant portion of the population. As a result, accessibility-oriented design becomes not only a technical requirement but also a social imperative.

2.2.3 Causes and Types of Mobility Impairments

This section discusses various types of disabilities that contribute to mobility impairments, which significantly affect an individual's quality of life and independence. These mobility barriers can be categorized into five main groups: neurological disorders, musculoskeletal conditions, injuries, obesity, and aging. Each category presents distinct symptoms and requires tailored approaches for effective management and inclusive design (Jansen et al., 2015; Laguna et al., 2024).

Neurological disorder: Neurological disorders involve conditions that affect the brain, spinal cord, and peripheral nerves. Common disorders such as Alzheimer's disease, Parkinson's disease, epilepsy, and stroke can result in motor dysfunction, memory loss, cognitive decline, seizures, and behavioral changes. These impairments can dramatically reduce personal autonomy and hinder everyday activities (Ashique et al., 2024).

Musculoskeletal conditions: Musculoskeletal conditions are chronic and degenerative disorders affecting bones, joints, muscles, and connective tissues. Conditions such as arthritis and osteoporosis can lead to stiffness, pain, and limited motion, particularly among older adults (Zhang et al., 2023). According to Cieza et al. (2020), in 2019, over 1.6 billion individuals aged 15–64 were affected by conditions requiring rehabilitation, with musculoskeletal disorders accounting for nearly two-thirds of those cases. These disorders negatively impact body function, daily activity, and social participation (Woolf & Pfleger, 2003).

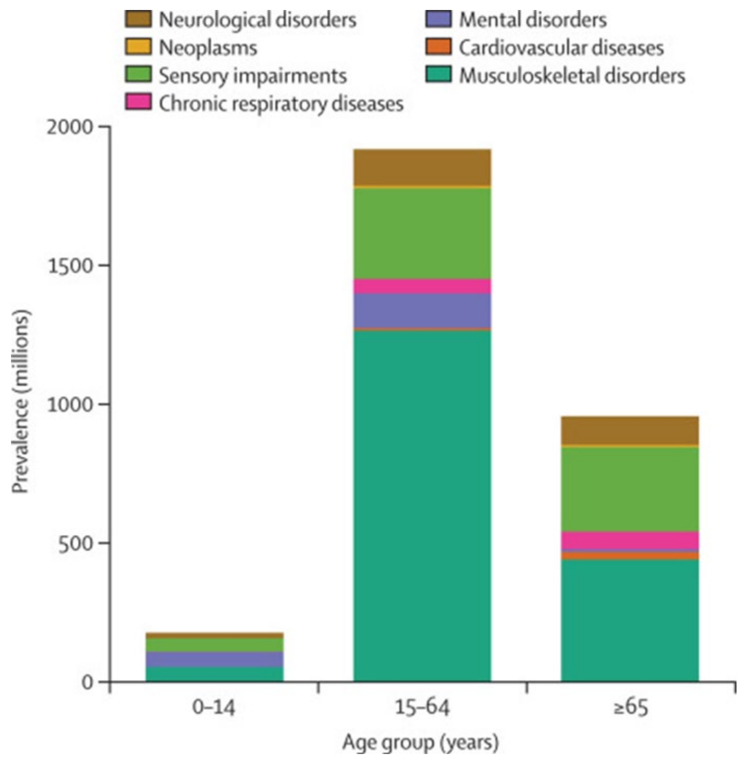


Figure 8. The worldwide count of existing cases requiring rehabilitation, along with the related years of life lived with disability by age and gender, including 95% uncertainty intervals for the years 1990 and 2019 (Cieza et al., 2020).

Injuries: Injuries are a major cause of both temporary and permanent mobility limitations. Individuals often reduce or cease driving due to injury-related constraints. Mobility limitations resulting from fractures, joint damage, or soft tissue injuries can necessitate the use of assistive devices such as wheelchairs or walkers. These limitations also contribute to social isolation, which is linked to poorer physical and mental health outcomes (Christie et al., 2017).

Obesity: Obesity is another significant factor contributing to mobility impairments. Excess body weight increases stress on joints and reduces endurance, balance, and movement efficiency. Obese individuals may struggle with tasks such as climbing stairs, walking long distances, or bending over. Severe obesity may require the use of mobility aids and contribute to the development of further functional limitations (Vincent et al., 2010; Wannamethee et al., 2005).

Aging: Aging is one of the most prevalent causes of mobility decline. As people age, physical strength, flexibility, and cognitive capacity gradually deteriorate. According to the WHO (2025), the global population over the age of 60 is expected to nearly double from 12% in 2015 to 22% by 2050. By 2030, one in six people worldwide will be aged 60 or older. Approximately 40% of older adults report difficulty performing daily tasks (Clark, 2023). In addition, sensory and cognitive decline can reduce the capacity to perform complex activities such as driving (Anstey et al., 2005).

Globally, over 1.3 billion people—roughly 16% of the world's population—live with significant disabilities. WHO (2023) reports that individuals with disabilities face transportation challenges 15 times more frequently than those without disabilities. As societies age, addressing the mobility needs of older people and disabled individuals becomes increasingly urgent—not only for the current generation but for future aging populations. It is, therefore, essential to develop transportation systems and environments that are inclusive by design and responsive to a wide spectrum of physical limitations.

2.2.4 Mobility Assist Aids for The Older People

People with mobility, circulatory, respiratory, or neurological impairments rely on various assistive technologies to enhance their independence and safety. These mobility devices play a crucial role in helping older individuals perform daily tasks and maintain autonomy (ADA, n.d.). Based on function and usage, mobility aids can be classified into three categories: wheelchairs, manually powered aids, and powered mobility devices.

Wheelchairs: Wheelchairs are either manually operated or powered devices primarily designed to assist individuals with significant mobility limitations. In the United States, approximately 2 million people use wheelchairs, half of whom are over the age of 65. Specifically, 2.9% of individuals aged 65 and above, and 5% of those over 70, are dependent on wheelchairs (Morrow, 2009). There are several types of wheelchairs tailored to specific user needs, including manual wheelchairs, electric-powered models, standing wheelchairs, and smart wheelchairs that incorporate navigation and sensory technologies (Avutu, Paul, & Reddy, 2023).

Manually Powered Aids: This category includes canes, walkers, and crutches, which provide support for individuals with minor to moderate balance or strength issues. These aids help to expand a user's base of support, enhance balance, and promote safe ambulation:

Walkers are suitable for patients with limited lower-body strength or those undergoing rehabilitation. However, their usability is often limited on stairs or uneven terrain.

Canes help users redistribute weight and maintain balance, making them particularly beneficial for those with mild instability.

Crutches are commonly prescribed for post-injury recovery and are used by approximately 6 million Americans. They encourage more physical activity than some other mobility aids, contributing to better long-term health outcomes (Bradley, 2011; Rasouli & Reed, 2020).

As illustrated in Figure 9, crutches can be categorized as axillary (underarm) or non-axillary based on user needs.

Beyond traditional aids, powered mobility devices include battery-powered scooters, fuel-powered carts, Segways, and All-Terrain Vehicles (ATVs) for use in specific environments. These devices enhance the range and independence of individuals with significant physical limitations. The Americans with Disabilities Act (n.d.) ensures the right to use such devices in public areas, unless doing so poses a safety risk.

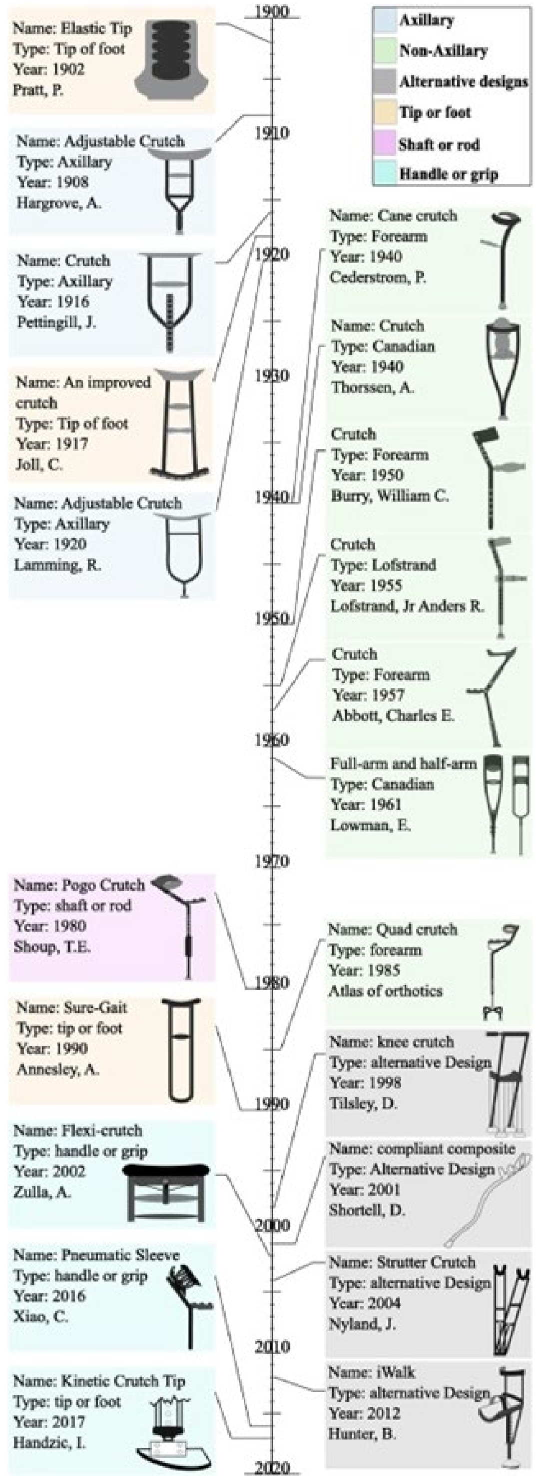


Figure 9. Timeline of crutch evolution through design modifications (Rasouli & Reed, 2020).

2.2.5 Trust and Emotional Needs

Trust has been widely recognized as a critical predictor of user acceptance in autonomous vehicle (AV) systems. It plays a dual role, both facilitating and hindering the adoption of AV technologies. Building trust is essential in older adults, who may be more skeptical of emerging technologies due to prior negative experiences, cognitive decline, or unfamiliarity with digital systems (Molnar et al., 2018; Zhang et al., 2019).

Thus, older users need to build calibrated trust. This requires an approach that enhances users' knowledge, understanding, emotional state, and prior experience (Lee & See, 2004). For older adults in particular, establishing appropriate levels of trust is essential to reducing resistance and encouraging sustained engagement with AV services. To enable users to handle FAV technology effectively, they must be sufficiently educated about it (Classen et al., 2021).

Research has shown that trust must be carefully calibrated. Both overtrust and undertrust can lead to suboptimal outcomes.

- **Overtrust** occurs when users place excessive confidence in the system beyond its actual capabilities, leading to unsafe behaviors and increased risk.
- **Undertrust**, on the other hand, leads users to avoid or reject useful technology, thereby limiting its benefits and reducing operational efficiency.

As users perceive this as a positive experience, distrust decreases, trust increases, and attitudes and perceptions towards future AV use are more likely to change positively.

To ensure equitable access and long-term adoption, AV designs must incorporate emotional reassurance, intuitive interactions, and transparent feedback mechanisms. These features contribute not only to immediate usability but also to long-term user satisfaction and social inclusion (Sun, Jing & Zhou, 2024).

2.2.6 Fear of Fully Autonomous Vehicles in the General Population

Over several years, surveys have consistently shown widespread fear and distrust of FAVs among the general public. According to a 2025 survey by the American Automobile Association (2025), about 60% of U.S. drivers reported fear of riding in a self-driving vehicle. The 2024 AAA survey found an even higher figure of 66%. Similarly, a 2017 Pew Research Center study revealed that 54% of Americans were concerned about autonomous vehicle development, and 56% said they would not want to ride in one (AAA, 2025; Smith & Anderson, 2017). Among respondents unwilling to use autonomous vehicles, 42% cited general distrust of technology or discomfort with ceding life-and-death decisions to machines, while 30% mentioned specific safety concerns (Smith & Anderson, 2017).

In summary, public fear of FAVs primarily stems from safety concerns, perceived accident risk, and a sense of loss of control. Nonetheless, many people acknowledge that FAVs could benefit older individuals by improving mobility and independence.

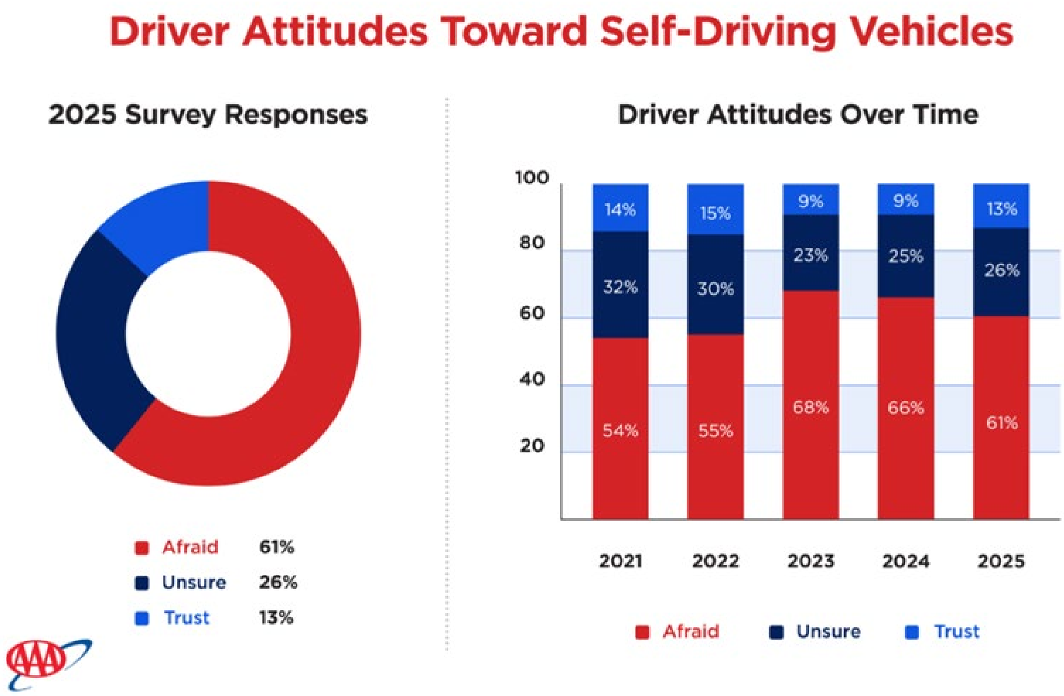


Figure 10. Statistics of Driver Attitudes Toward FAVs (AAA, 2025).

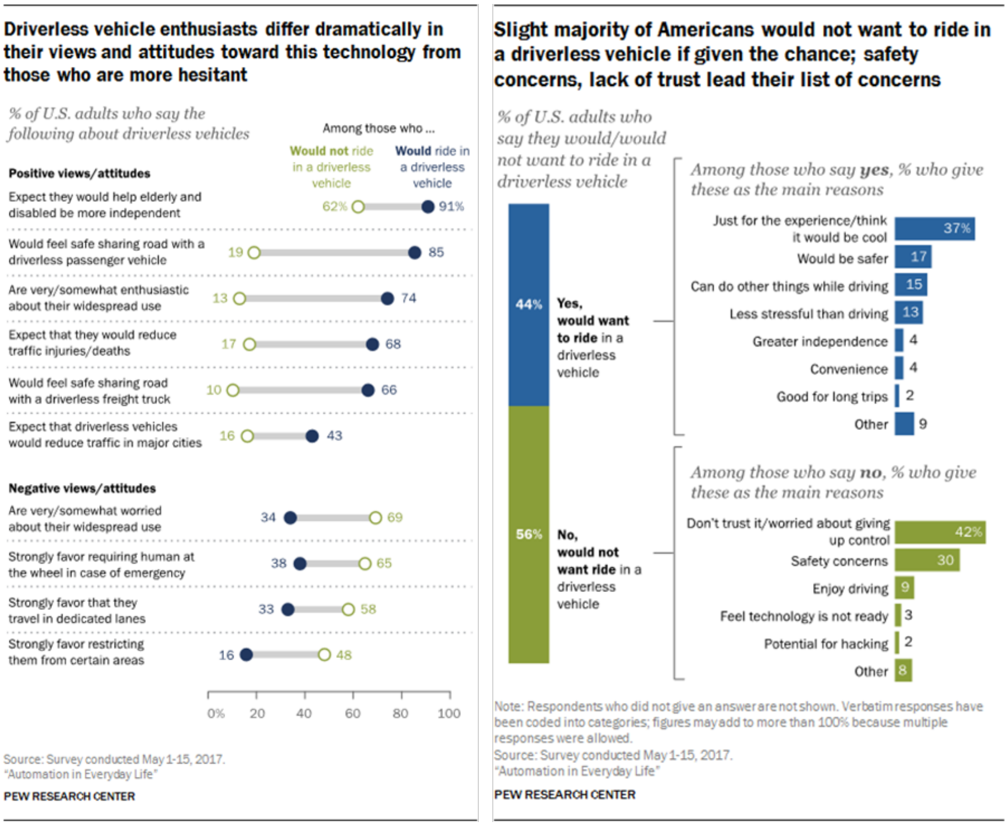


Figure 11. Key Public Concerns Regarding FAVs (Smith & Anderson, 2017).

2.2.7 Fear of Fully Autonomous Vehicles in the Older People Population

Older individuals exhibit greater resistance and fear toward new technologies, including autonomous vehicles, compared to younger populations. This is not merely due to conservatism but reflects a combination of factors, including digital literacy, health conditions, economic limitations, and psychological barriers. According to a 2021 Pew Research Center survey, 56% of adults aged 50 and older believed autonomous technology could reduce travel-related stress, and 72% thought it could help older adults and people with disabilities live more independently. Despite these potential benefits, 53% of those aged 50 and above viewed widespread AV use as a negative development for society, compared to 37% among younger adults. Furthermore, 74% of older adults stated they would not want to ride in an AV, while only 52% of adults under 50 expressed the same (Smith & Anderson, 2021).

The main causes of fear among older adults include safety and trust issues, low digital literacy, and technological anxiety. Many older participants reported perceiving AVs as unsafe and requested more safety evidence, often citing media-reported accidents as justification. Complex interfaces, small buttons, and non-intuitive designs pose additional barriers, as technologies are rarely designed with age-related sensory or cognitive changes in mind (Zhang, 2023).

In studies examining older people's willingness to use autonomous taxis, participants expressed a desire for manual override options or for an onboard operator to assist in emergencies. They also expressed concerns about making mistakes while using the technology, privacy breaches, and difficulty understanding technical terminology or complicated interfaces (Zhang, 2023).

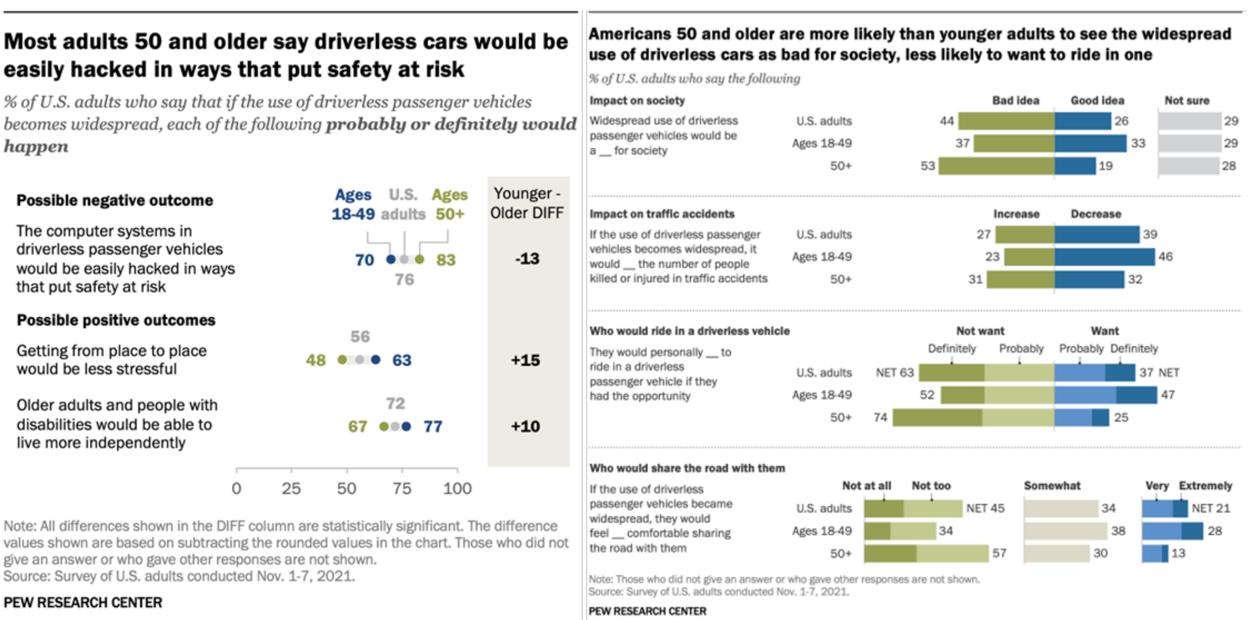


Figure 12. Key Concerns of Older People Regarding FAVs (Smith & Anderson, 2021).

2.3 Socially Stigmatized Products and Ageism Services Designed for Older Adults

According to previous studies, designs for older people have evolved based on clear ergonomic and cognitive foundations, including enhancing visual contrast, simplifying interfaces, adjusting response times, and strengthening physical stability (Fisk et al., 2009; Norman, 2013).

However, it has been repeatedly reported that, in actual use contexts, such rational designs are not always socially accepted. Instead, they often reinforce negative stigmas. Various items, such as emergency alert systems, mobility aids, adult diapers, and senior-specific digital devices, were thoughtfully designed to meet the physical and cognitive needs of older adults. However, in social settings, these products are often viewed as symbols of "dependency," "frailty," and "incompetence." These negative perceptions are not caused by the products' functional limits, but are instead closely linked to social identity concerns that users develop through their use (Lee & Coughlin, 2015).

2.3.1 Examples of Stigmatized Products and Services Designed for Older Adults

Despite having the clear objective of ensuring the safety of older adults, emergency response systems and fall detection devices often trigger psychological resistance. This is because wearing such devices may lead users to be perceived as ‘an individual in need of assistance’ (Lee & Coughlin, 2015). Users perceive that wearing this device exposes them to others as individuals at risk of an accident at any time.

In particular, wearable safety equipment can negatively affect a user’s self-identity as it becomes increasingly visible to others (Peek et al., 2014).

Figure 13. Bad Stigmatized Emergency Device (Good Life Sorted, 2025).

While the Apple Watch offers advanced health features like ECG, fall detection, and medication alerts, it uses ‘Invisible Design Features’ to position itself as both a fashion accessory and a fitness gadget. This strategy enables the technology to deliver its helpful functions while remaining discreet (Choi Design Editorial, 2025).

Figure 14. Apple’s Invisible Design Feature (Choi Design Editorial, 2025).

Walking aids show a similar pattern. While canes and walkers have been proven effective in preventing falls and improving mobility, in many cultures, they function as visual symbols of frailty and dependence (WHO, 2025). Older adults are also reluctant to use walking aids due to their associations with aging and dependency (Gooberman-Hill & Ebrahim, 2007). This social interpretation leads users to delay using assistive devices despite their actual need, ultimately increasing safety risks.

Nordic walking poles exemplify a design that successfully overcomes social stigma while fulfilling their original functional purpose of supporting health. By using two poles, this activity redefines the equipment's value as a component of dynamic full-body exercise and outdoor leisure. Consequently, what was once perceived as a clunky assistive device has been transformed into a sophisticated lifestyle tool (Takeshima et al., 2013).

Figure 15. Nordic walking poles (Cleveland Clinic, 2022).

Adult diapers are one of the product categories that face the greatest psychological resistance and social stigma in senior-centered design. Adult diapers, also known as absorbent underwear, are frequently stigmatized as symbols of ‘aging’ and ‘unhygienic’ behavior, despite their practical necessity. This stigma causes users to emphasize social acceptance over the product's actual benefits, potentially reducing their quality of life. Kimberly-Clark's Depend and Yuhan-Kimberly have excluded the term "diaper" from their marketing, instead using terms such as ‘underwear’ or ‘panties,’ thereby repositioning the product from an assistive device for patients requiring treatment to a category of everyday clothing. Their advertisements showcase active older adults engaged in sports and social events, transforming incontinence care from a ‘shameful disease management’ problem into an aspect of ‘everyday etiquette for active social participation’ (Fisher, 2022; Kimberly-Clark, 2017).

Figure 16. Anti-Stigmatized Depend Diaper for Adult (Depend, n.d.)

While older-people-friendly mobile phones and simplified interfaces are designed to reduce cognitive load, excessive simplification and the explicit labeling of these devices as "for older people" can result in users being perceived as a technologically incompetent group. Some users perceive themselves as "excluded from technological advancements" when using these products, a major factor hindering adoption (Rogers, 2019).

To address these issues, instead of creating separate hardware for specific age groups like Jitterbug, companies are reducing age-related stigma by adding features such as larger text, voice recognition, and adjustable response speeds to existing products. For instance, smartphone accessibility options, customizable interface speeds, and voice-based interactions are developing in ways that cater to older adults' needs without specifically targeting any age group (Apple, 2023; Google, 2022).

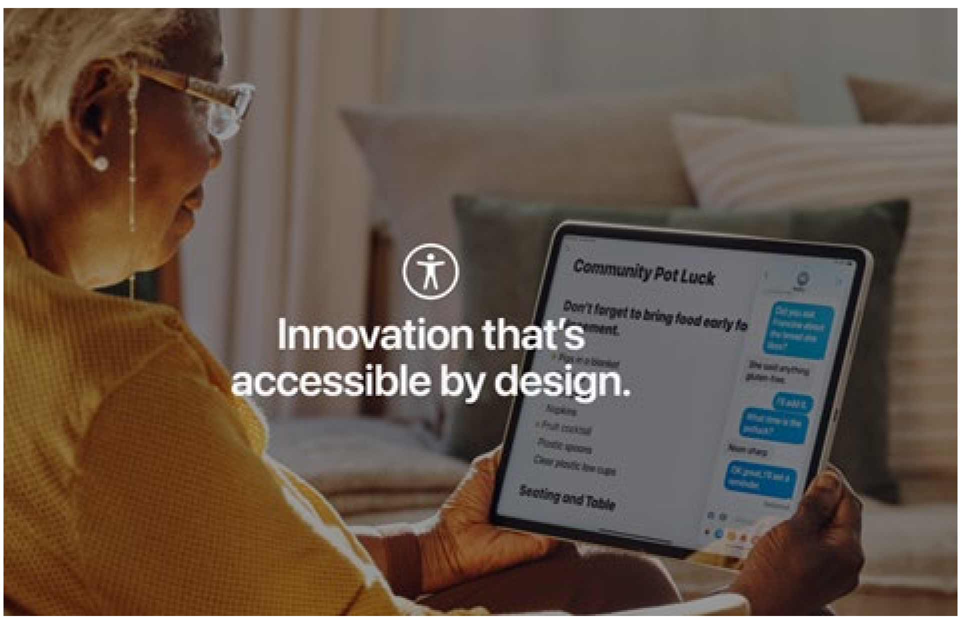


Figure 17. Apple’s accessibility (Apple, 2023).

In conclusion, the success of products and services for older adults hinges more on their social interpretability than on their functional completeness. Therefore, future design research and practice must move beyond analyzing physical and cognitive needs to critically examine the social positioning a design imposes on its users.

Table 1. Chart analyzing products/services for older people and examples of negative perceptions.

Product / Service	Emergency alert wearables	Mobility aids	Adult incontinence products	Senior-specific mobile phones
Physical Features	Small wearable device, fall detection sensors	Height-adjustable, stability-focused	High-absorption, discreet materials	Large buttons, high contrast
Cognitive / HMI Features	One-touch interaction, automation	Minimal learning required	Simple wearing mechanism	Simplified UI, reduced options
Social Meaning	Dependence, vulnerability	Frailty symbol	Loss of dignity	Technological incompetence
Positive Factors	Increased safety, rapid response	Improved mobility, fall prevention	Improved hygiene, QoL	Ease of use
Negative Stigmatizing	Stigmatization, identity threat	Social pity, self-stigma, Identity labeling as "old"	Shame, aging stigma	Identity labeling as "old"
Solving stigmatizing	Invisible Design	Changing the product image to exercise and outdoor leisure	Changing the brand's image to underwear and healthy	Give options to change what they want

2.4 Related Concepts and Design Principles

This section covers a range of design concepts and principles to consider when designing inclusive FAVs for older users. The design principles are based on a user-centered approach, focusing on human physical and cognitive characteristics and accessibility for older people and people with disabilities.

2.4.1 Human Factors

Human Factors is a concept that seeks to understand human abilities and limitations and apply them to technologies and systems (HFES, n.d.). To establish effective human factors, the user's abilities, such as Sensory, cognitive, and physical, must be considered. In addition, the environment and process are essential to achieving successful design (Farmer et al., 2022). Fig 18 shows examples of human factors,

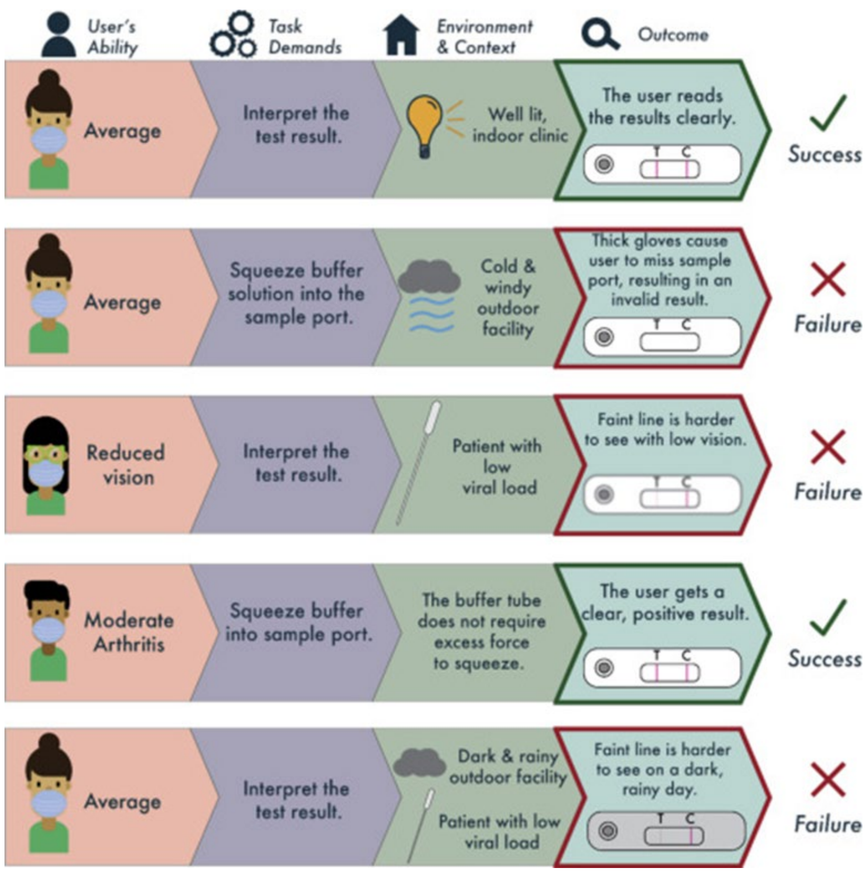
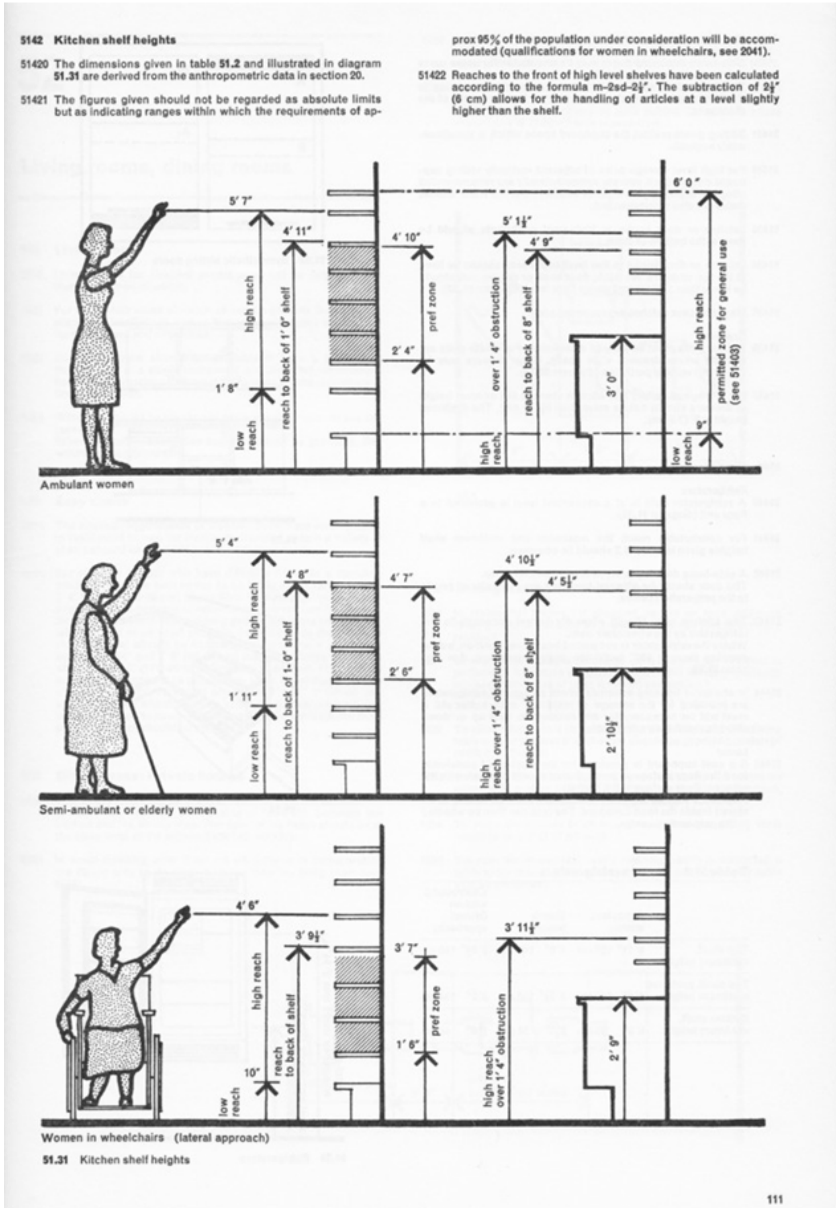


Figure 18. Human factors inputs and outcomes (Farmer et al., 2022).

2.4.2 Designing for People with Disabilities

Designing for the Disabled was established as a field by Selwyn Goldsmith in 1963 in a book by the same name. This is not only the first book that considers disability as a design target, but also the first publication for designers aimed at people with disabilities. This book addresses accessibility issues in public spaces, public buildings, and homes, as well as anthropometric and ergonomic analyses for wheelchair users, people using crutches, and people using various mobility aids in daily life (Guffey, 2020).


5142 Kitchen shelf heights

51420 The dimensions given in table **51.2** and illustrated in diagram **51.31** are derived from the anthropometric data in section 20.

51421 The figures given should not be regarded as absolute limits but as indicating ranges within which the requirements of approx 95% of the population under consideration will be accommodated (qualifications for women in wheelchairs, see 2041).

51422 Reaches to the front of high level shelves have been calculated according to the formula m–2sd–2½″. The subtraction of 2½″ (6 cm) allows for the handling of articles at a level slightly higher than the shelf.

51.31 Kitchen shelf heights

111

Figure 19. Kitchen Shelf Heights, from Goldsmith, *Designing for the Disabled*, 2nd ed., 111 (Guffey, 2020).

2.4.3 Aging in Place

As time goes by, older people increasingly tend to stay in the areas and communities where they grew up for as long as possible. According to the National Institute on Aging (n.d.), this phenomenon is defined as "Aging in Place". Aging in Place is a broader concept than universal design or the Americans with Disabilities Act (ADA). Design for aging in place helps designers understand the fears of isolation, dependency, and depression that older people experience as they become more dependent on family and friends during the aging process. This extends to understanding how the body responds to aging and providing solutions to address the psychological and social issues associated with aging (Lawlor & Thomas, 2008).

2.4.4 Universal Design

In the United States, Ron Mace, an architect, coined the term Universal Design, which aimed to focus on accessible housing with a universal design approach (CEUD, n.d.). Universal Design aims to improve human performance and quality of life (Elnagar et al., 2024).

The Center for Excellence in Universal Design (n.d.) Identified that:

> Universal Design is the design and composition of an environment so that it can be accessed, understood, and used to the greatest extent possible by all people regardless of their age, size, ability, or disability. An environment (or any building, product, or service in that environment) should be designed to meet the needs of all people who wish to use it. This is not a special requirement for the benefit of only a minority of the population. It is a fundamental condition of good design.

From 1994 to 1997, the Center for Universal Design (CUD), funded by the U.S. Department of Education’s National Institute on Disability and Rehabilitation Research (NIDRR), established the seven principles of universal design. The resulting Principles of Universal Design were as follows:

Principle 1. Equitable Use: The design is valuable and marketable to people with diverse abilities.

Principle 2. Flexibility in Use: The design accommodates a wide range of individual preferences and abilities**.**

Principle 3. Simple and Intuitive Use: Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

Principle 4. Perceptible Information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Principle 5. Tolerance for Error: The design minimizes hazards and the adverse consequences of accidental or unintended actions.

Principle 6. Low Physical Effort: The design can be used efficiently and comfortably with minimal fatigue.

Principle 7. Size and Space for Approach and Use: Appropriate size and space are provided for approach, reach, manipulation, and use regardless of the user's body size, posture, or mobility (Ostroff, 2011).

(Figures 20,21 for more information)

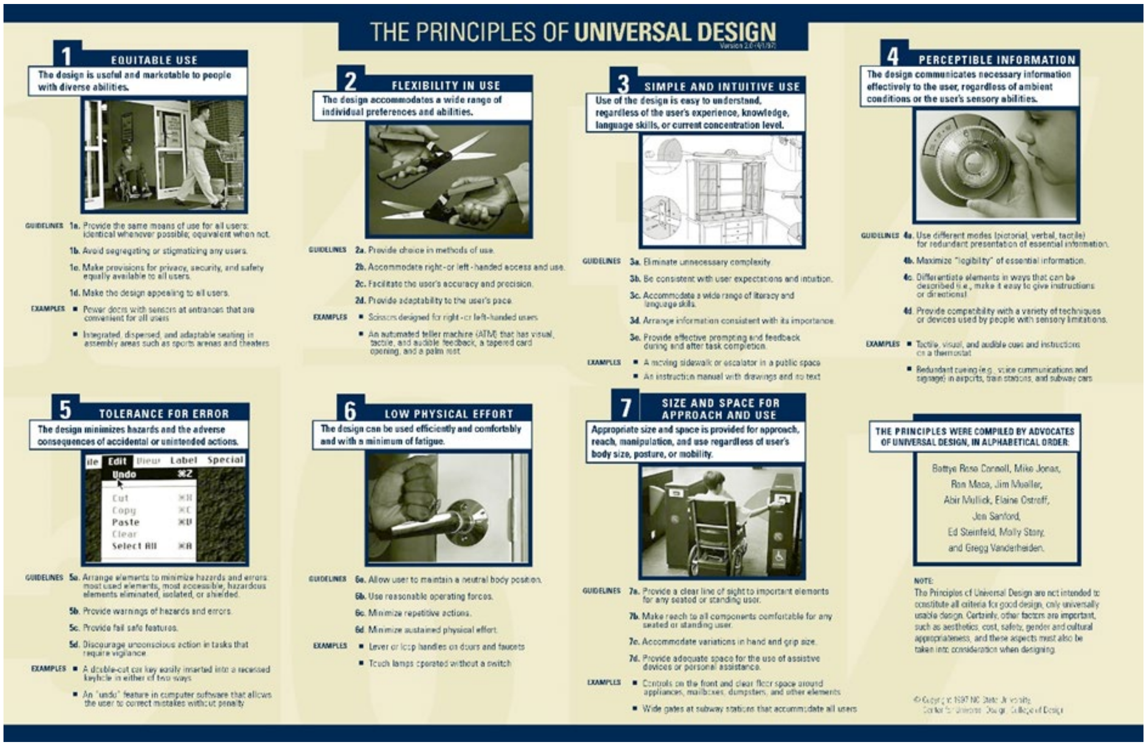


Figure 20. The Principles of Universal Design (CUD, 1997).

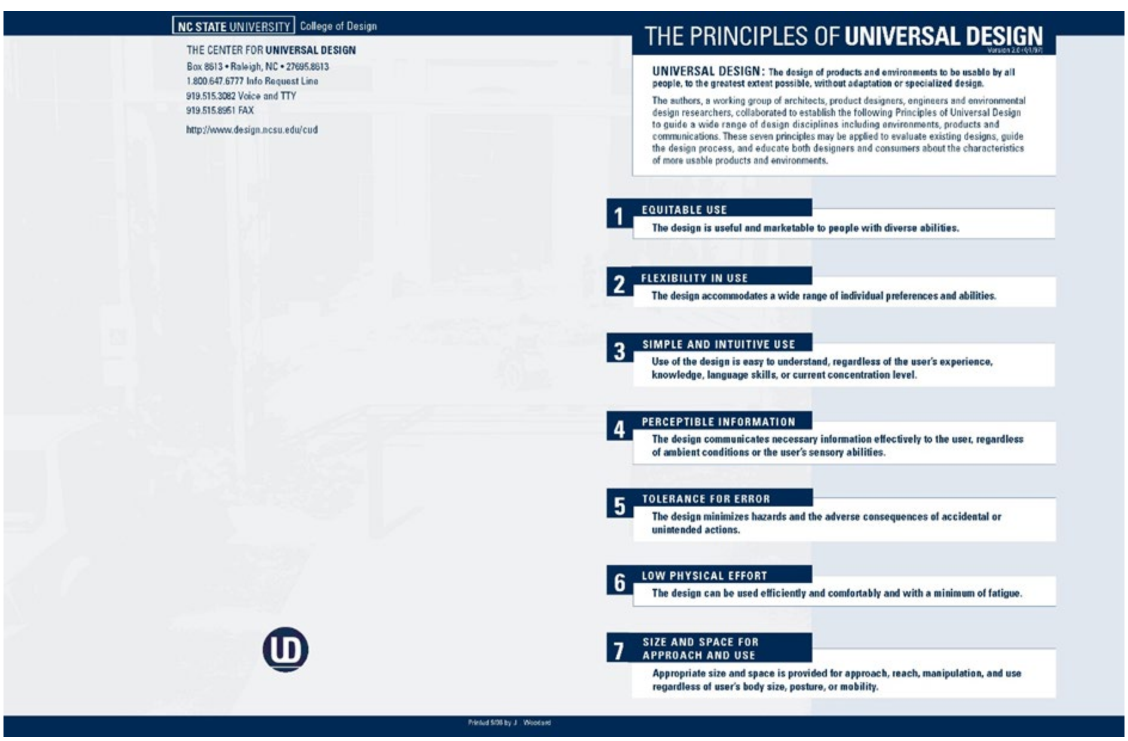


Figure 21. The Principles of Universal Design (CUD, 1997).

2.4.5 Accessible Design

Accessible design is a concept derived from the adoption of the first Americans with Disabilities Act (ADA) Accessible Design Standards in 1991, known as the "1991 ADA Standards", and the revised ADA Standards in 2010, known as the "2010 ADA Standards" (ADA, n.d.). Accessible design is a user-centered approach that focuses on adapting products, services, and environments to make them easier to use for everyone, including people with disabilities. This approach goes beyond complying with accessibility standards or completing checklists to ensure that all users can interact with and understand the design without special modifications or additional assistance, regardless of physical or cognitive limitations (Persson et al., 2015).

The International Organization for Standardization (ISO) defines accessible design as:

- Products and environments that are easy for users to use.
- Products or services adapted for multiple users.
- Products for people with disabilities and standardized interfaces that are compatible with those products (ISO, 2001).

Accessible design now applies not only to physical products but also to digital environments, including websites. The Web Content Accessibility Guidelines (WCAG), developed by the World Wide Web Consortium (W3C), establish standards to ensure that web applications and other digital assets are accessible. As the internet has become integral to daily life, these guidelines are essential for making online resources usable for all individuals (W3C, n.d.).

2.4.6 Inclusive Design

Inclusive design is an approach focused on creating products and experiences that are accessible, usable, and understandable by the broadest possible range of people. It extends beyond basic accessibility by considering users' different needs, backgrounds, and experiences (Interaction Design Foundation, 2016). This term originates from “The Case for Inclusive Design (1994)” presented by Roger Coleman (Kille-Speckter & Nickpour, 2022). While universal design and accessible design are seen as more focused on people with disabilities, inclusive design includes a broader range of people, including those of different ages, races, and genders.

(For details, refer to Fig. 22).

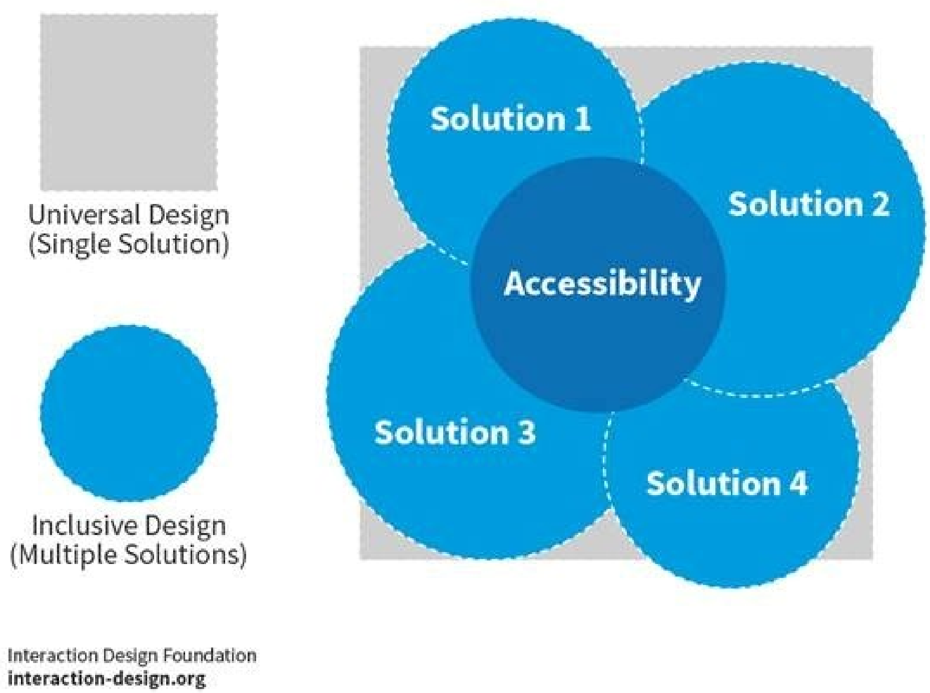


Figure 22. Scope of Inclusive Design (Interaction Design Foundation, 2016).

Microsoft (n.d.) has defined three main principles of inclusive design, reproduced here and in Figure 23:

Recognize Exclusion: We may not realize it, but all of us have biases—it is human nature. If we design solutions for user problems without recognizing these biases, we will end up excluding certain groups of people. Note that this is not limited to physical disabilities. It can apply to other forms of exclusion, such as social participation or temporary impairments.

Learn from Diversity: Inclusive Design puts people at the center throughout the process. Involving people from different communities throughout the design process will help you gain fresh, diverse perspectives.

Solve for One, Extend to Many: When you design a feature with one group in mind, you can expand the scope to help others who can benefit from it.

(For more details, refer to Fig. 23).

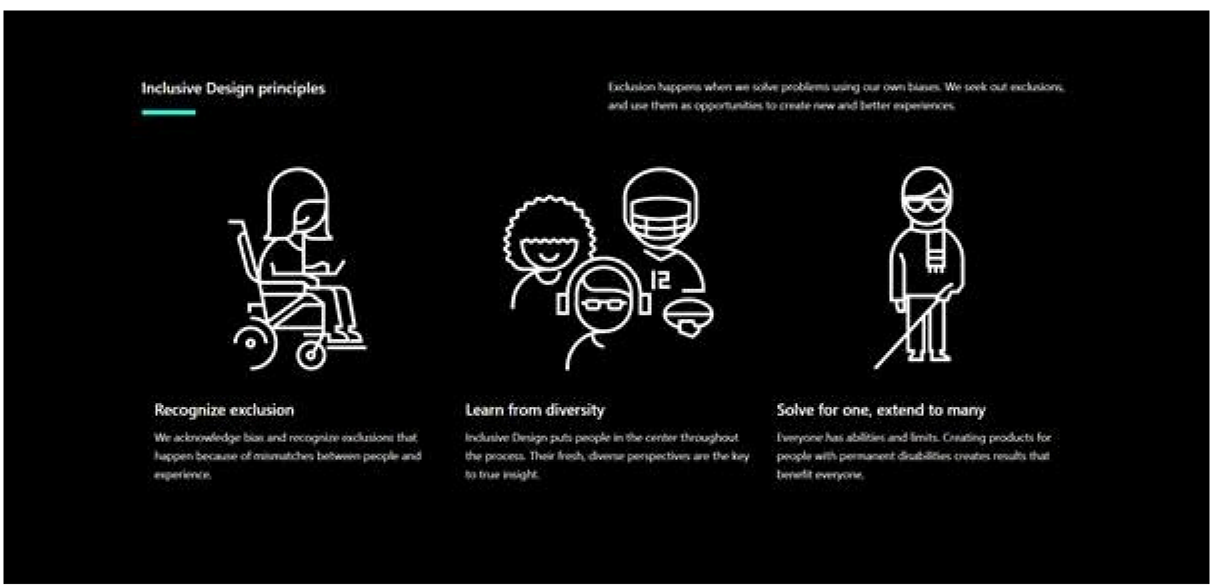


Figure 23. Inclusive Design Principles (Microsoft, n.d.).

In 2017, accessibility experts Henny Swan, Ian Pouncey, Heydon Pickering, and Léonie Watson established seven principles of inclusive design, listed below:

Provide comparable experience

Give control

Offer Choice

Consider situations

Be consistent

Priorities content

Add value

(For more details, refer to Fig. 24).

Figure 24. 7 Principles of Inclusive Design (Business Disability Forum, 2026).

2.4.6.1 Inclusive Design Promotes Anti-Stigmatization

Inclusive design focuses on developing environments and products that are more accessible and user-friendly for a diverse group of people without the need for special adaptations. A fundamental idea of Inclusive design is to ensure accessibility without stigma by seamlessly incorporating features that assist all users and remain unobtrusive. For instance, automatic sliding doors are common in many shopping malls. They eliminate obstacles for wheelchair users, older adults, and young children who find heavy doors hard to open. Additionally, they assist all customers carrying shopping or other items, providing convenience for those without free hands. These doors promote accessibility without stigma, as everyone uses them when entering or leaving the store, regardless of ability (Carr et al., 2013).

In contrast, designs that visually mark users as "frail" (e.g., clinical-looking devices or obvious wheelchair lifts) can trigger stigma. Design research finds that older adults often avoid technologies that signal "serious impairment" (Li et al., 2020).

This model provides a theoretical framework that explains how product design elements can pose an identity threat to older users and ultimately be perceived as a stigma. It emphasizes that designers should not only focus on a product's "functionality" but also comprehensively understand the symbolic meanings it conveys about the user's social identity (Li et al., 2020).

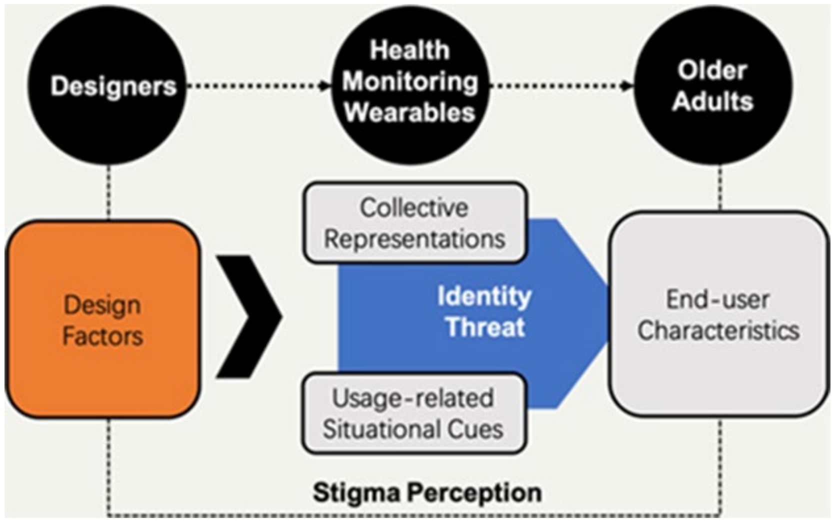


Figure 25. Research Model for Deconstructing Stigma Perception Modified from Major and O'Brien's (2005) Stigma-Induced Identity Threat Model (Li et al., 2020)

In Design Factors, the four key components and mechanisms of the model are as follows:

- **Lack of aesthetic appeal**

Inharmonious color schemes, inferior materials, and unconventional or unstylish designs can provoke negative reactions from users.

- **Accentuated Social Signifiers**

An overly noticeable SOS button, designs suggesting particular illnesses like dementia, and common older people styles can label users as vulnerable individuals in need of help.

- **Poor Affordance**

Using unoptimized operating procedures or socially inappropriate methods, like speaking loudly into the watch, can make users feel embarrassed.

- **Neglect of Privacy**

Excessive interference with daily activities or the sharing of data without user consent can lead users to feel their autonomy is being compromised (Li et al., 2020).

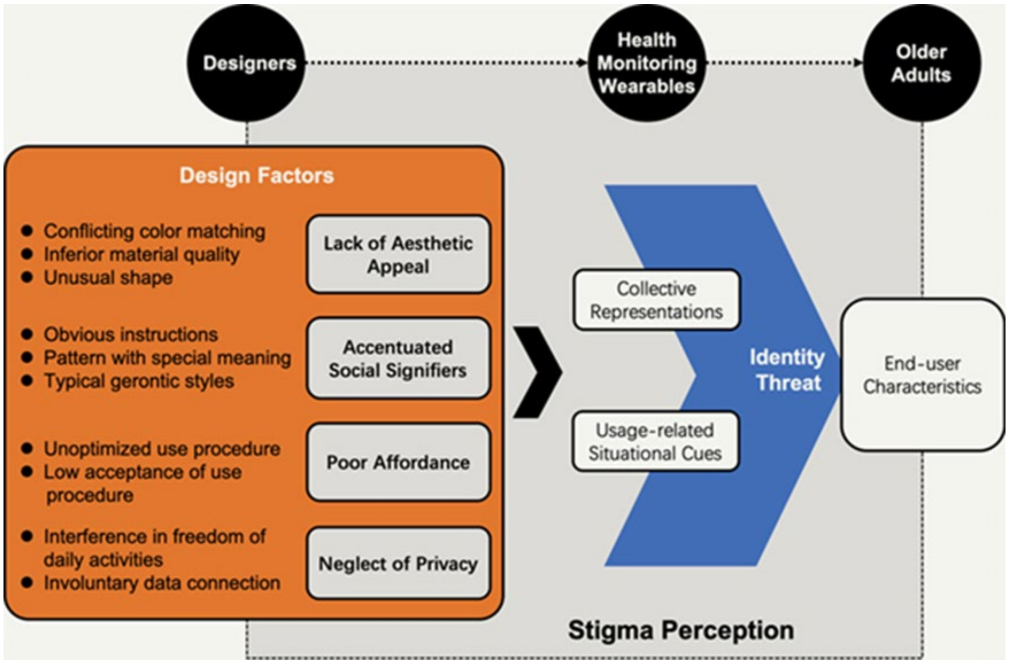


Figure 26. Conceptual model of stigma perception in a design domain (Li et al., 2020).

2.4.6.2 Key Takeaways: Inclusive Design Promotes Anti-Stigmatization

Inclusive design transcends mere functional accessibility. It serves as a powerful tool for social integration by dismantling the visual and psychological barriers associated with 'special' or 'assistive' products. By prioritizing universal usability, design can effectively eliminate the stigma often attached to aging and disability. These goals can be achieved through the following guidelines.

Mainstream Features for Everyone: Incorporate everyday solutions, such as level boarding and intuitive controls, that are accessible to all. Universal design examples, such as automatic doors and curb-height ramps, assist both older and younger users without any stigma (Carr et al., 2013).

Aesthetic Appeal: Design assistive elements to resemble typical vehicle features. Using high-quality finishes, warm interiors, and stylish seats and handles helps the vehicle appear as a regular community resource rather than a "disabled shuttle." Research indicates that insufficient aesthetic appeal and overt "signifiers" of disability can lead to stigma, so designers aim for appealing shapes and finishes (Li et al., 2020).

Flexibility & Personalization: Designing systems that adapt to individual needs, such as color contrast, font size, and audio guides, rather than imposing a single "one-size-fits-all" solution, helps reduce the need for special adaptations that can emphasize differences (Oxley Agency, 2024).

Avoiding Stereotypes: Actively challenging unconscious biases in content and functionality to prevent reinforcing harmful oversimplifications about groups of people, notes (Naghdali et al., 2025).

Multi-modal, Familiar Interfaces: Offer controls and information that do not assume disability. For example, combining voice announcements, large, easily readable displays, and physical buttons enables older riders with varying abilities to participate normally (Naghdali et al., 2025).

Ultimately, anti-stigmatization in design is achieved when the user's limitations are no longer the focal point of the interaction. Inclusive design fosters an environment where technology discreetly supports users, ensuring that dignity and social belonging are preserved alongside physical mobility.

2.4.7 Interaction Design

Bill Moggridge and Bill Verplank coined the term "Interaction Design" in the 1980s. Bill Moggridge later changed the field called ‘SoftFace’ to interaction design. Bill

Moggridge defined interaction design as "The design of the subjective and qualitative aspects of everything that is both digital and interactive" (Moggridge, 2007, p. 660). Interaction design can be felt broadly, including elements such as aesthetics, movement, sound, and space (Interaction Design Foundation, 2024).

Bill Verplank (2009) defines interaction design as:

> Interaction design is a profession that will mature in the 21st century. The central concern is how to design for people, for their physical and emotional needs, and increasingly for their intellect. With computers, we can make products that take on almost any behavior. (p.6)

Verplank (2009) argues that successful interaction design must use a variety of methods and representations and balance them.

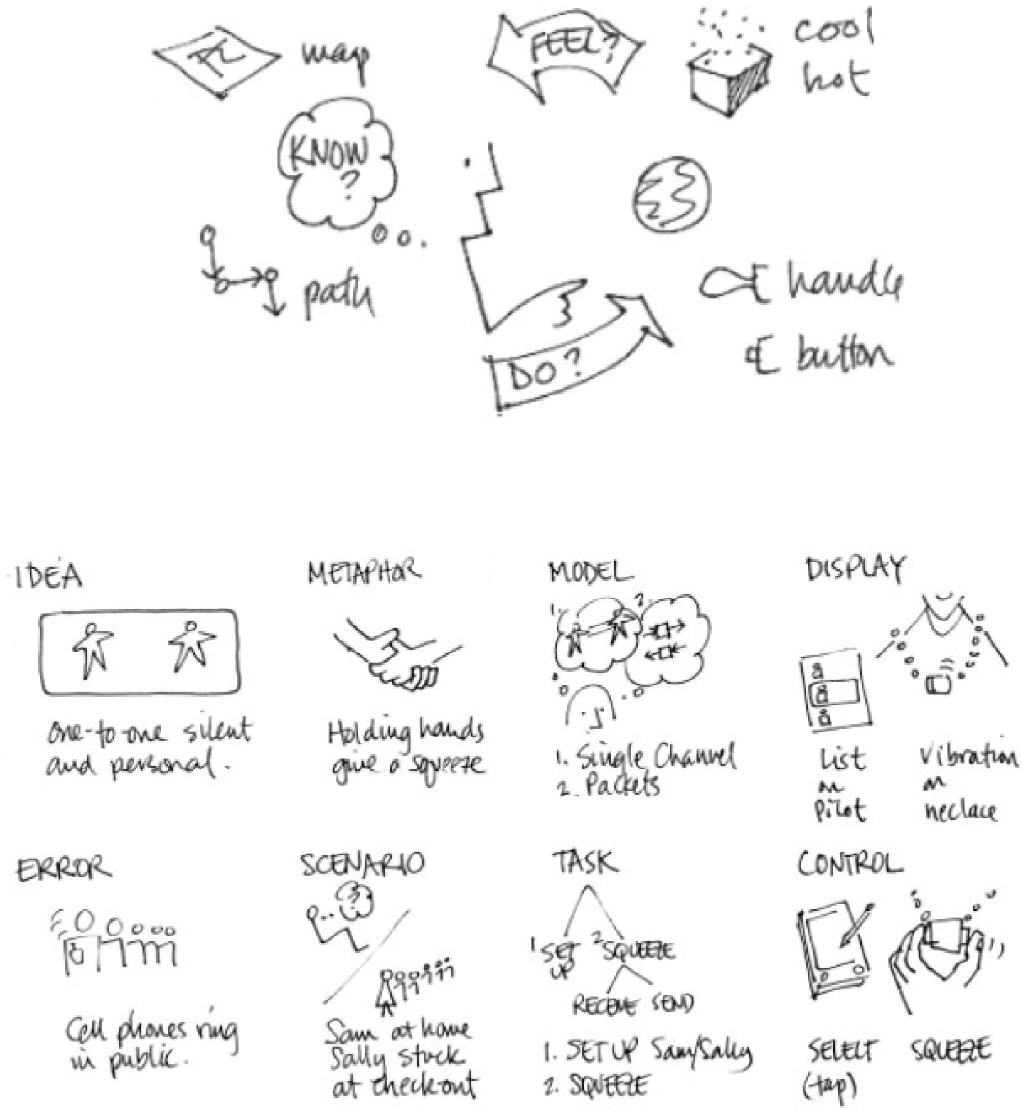


Figure 27. Interaction Design Framework (Verplank, 2009, p.12).

2.4.8 Human-Centered Design

Human-centered design (HCD) or user-centered design (UCD) was popularized by *User Centered System Design: New Perspectives on Human-Computer Interaction,* written by Don Norman and Stephen W. Draper in 1986. After a few years, Norman (1988) developed the UCD concept further in his book *The Psychology of Everyday*

Things (POET). User-centered design (UCD) is an iterative design process focused on the users and their needs (Interaction Design Foundation, 2016).

In the POET, Norman (1988) suggests seven fundamental principles of design:

- Discoverability
- Feedback
- Conceptual model
- Signifiers
- Mappings
- Constraints
- Affordances

Affordance, one of the seven principles of design, is considered a critical core element in design principles. Affordance is a design element that enables users to intuitively understand and use a product, dramatically affecting the user experience. The following section explores the concept of affordance and its importance in more detail.

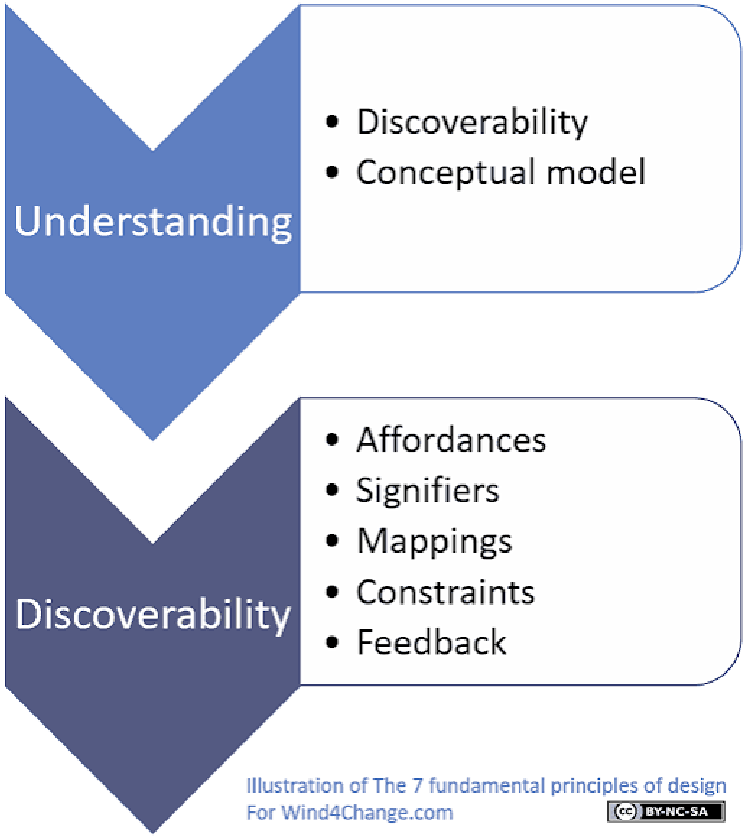


Figure 28. The Seven Fundamental Principles of Design (Eric, n.d.).

2.4.9 Affordance

Affordance was introduced by psychologist James Gibson in 1977 and later introduced to the HCI field by Don Norman in 1988 (Gibson, 2000; Norman, 1988). Affordance is the understanding, evaluation, and interpretation of objects through experience or perception. Through this, users can know what characteristics or functions an object has (Interaction Design Foundation, 2015).

In POET, Norman (1988) said of affordances:

> ...the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could be used. [...] Affordances provide strong clues to the

operations of things. Plates are for pushing. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing. When affordances are taken advantage of, the user knows what to do just by looking: no picture, label, or instruction needed. (p.9)

In POET, affordance is divided into two types: real affordance and perceived affordance, and Rex Hartson divided this concept into four types of affordances (Hartson & Pyla, 2018):

Physical: Physical affordances help users to easily perform actions such as clicking, touching, pointing, gesturing, and moving objects. These affordances make users' physical interactions more intuitive and convenient.

Figure 29. Example of Physical Affordance (Hartson & Pyla, 2018).

Cognitive: Cognitive affordances assist users in executing cognitive activities, including thinking, decision-making, learning, memory, and comprehension. This facilitates users' access to and processing of information.

Figure 30. Example of Cognitive affordance (Hartson & Pyla, 2018).

Sensory: Sensory affordances help users perform activities that utilize multiple senses, such as sight, hearing, and touch (or taste and smell). These affordances support the perception of information through the senses, allowing users to interact effectively with their surroundings.

Functional: Effective functional support enables users to carry out tasks, including recreational activities, complete objectives, and navigate system requirements with ease. This allows users to achieve their goals and utilize the system efficiently and effectively (Hartson, & Pyla, 2018).

Each type of affordance should be identified independently and considered under its unique conditions. Each type of affordance operates through different mechanisms, induces different types of user behavior, and has distinct implications for evaluating design requirements and diagnosing problems (Hartson & Pyla, 2018).

2.4.10 Design Insights for Effective Autonomous Vehicle Interface Design

Recent studies on designing digital interfaces for older people emphasize the importance of reducing cognitive load and building user trust to minimize technology anxiety.

The Flourish Best Practice Report outlines ten design principles originally created for Human–Machine Interfaces (HMIs) in autonomous vehicles. However, these principles can also serve as strategic guidelines to increase older adults' confidence and willingness to adopt new technologies (Designability Charity, 2019). The principles collectively address the cognitive, emotional, and psychological barriers that lead to older users' hesitance toward emerging technologies.

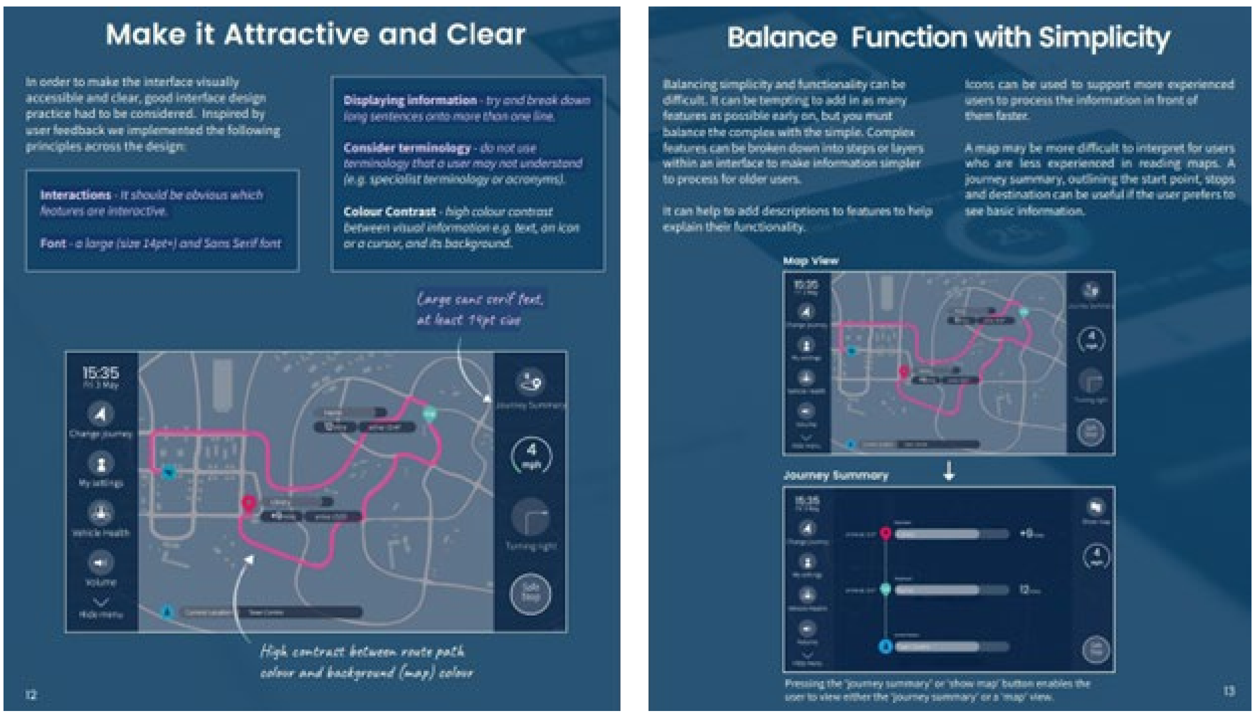


Figure 31. Accessible UI Design Guidelines 1 & 2 (Designability, 2019, p. 12,13).

- **Make it Attractive and Clear.**

A visually clean and straightforward interface reduces anxiety and mental effort. High contrast, large fonts, and clear icons help users quickly find essential information.

Simplified onboarding screens can make unfamiliar technologies feel approachable rather than intimidating (Designability, 2019)

- **Balance Function with Simplicity**

Older adults might find too many features overwhelming. Functions should be organized into clear steps or optional layers (basic versus detailed views) to maintain high usability while reducing complexity (Designability, 2019).

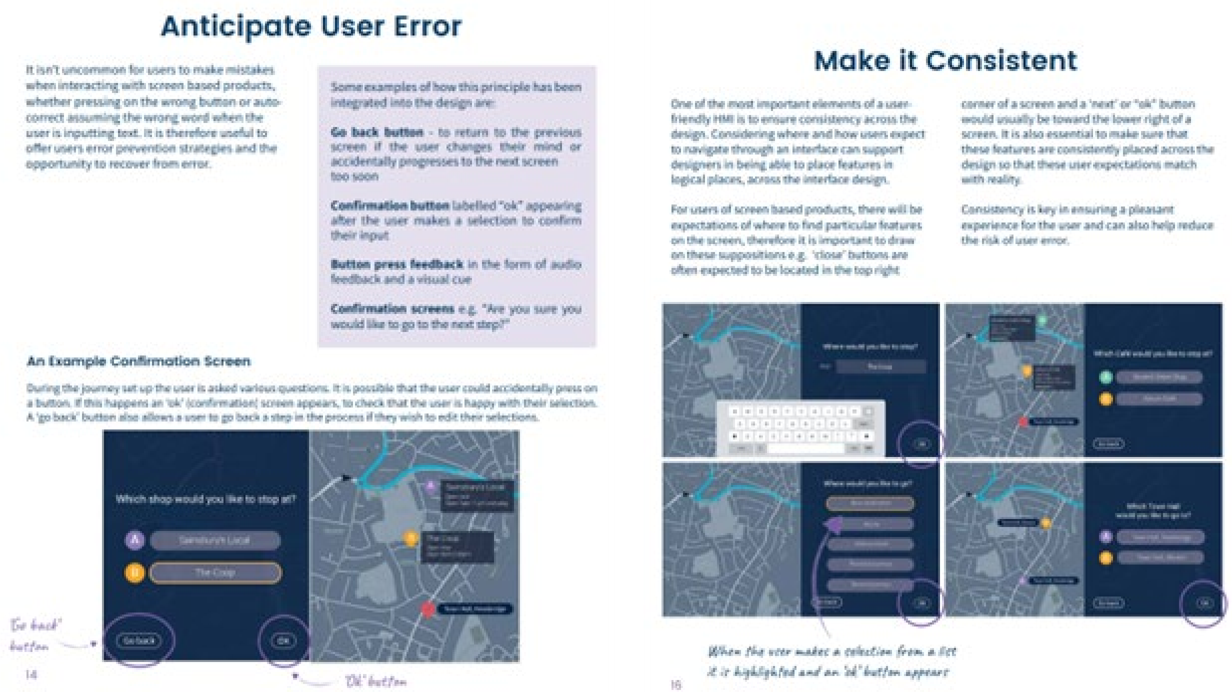


Figure 32. Accessible UI Design Guidelines 3 & 4 (Designability, 2019, p. 14,15).

- **Anticipate User Error**

Systems should enable users to predict and recover from errors easily by providing clear "Go back" and "Confirm" buttons. Simplified error correction reassures users and boosts their confidence in using the system (Designability, 2019).

- **Make it Consistent**

Maintaining consistency in layout, icons, and button placement enhances predictability and shortens the learning curve. Recognizable patterns, such as standard button locations or interface flow, help older users feel more confident and secure (Designability, 2019).

Figure 33. Accessible UI Design Guidelines 5 & 6 (Designability, 2019, p. 17,19).

- **Make it Flexible**

Interaction methods should support diverse physical and cognitive abilities. Offering multiple input options, such as touchscreen, voice, or physical buttons, ensures good redundancy, giving users the flexibility to select the most comfortable method (Designability, 2019).

- **Keep the User Informed**

Transparency about system actions enhances trust. Real-time updates (e.g., Obstacle detected, slowing down) help users understand what the system is doing and why, reducing uncertainty (Designability, 2019).

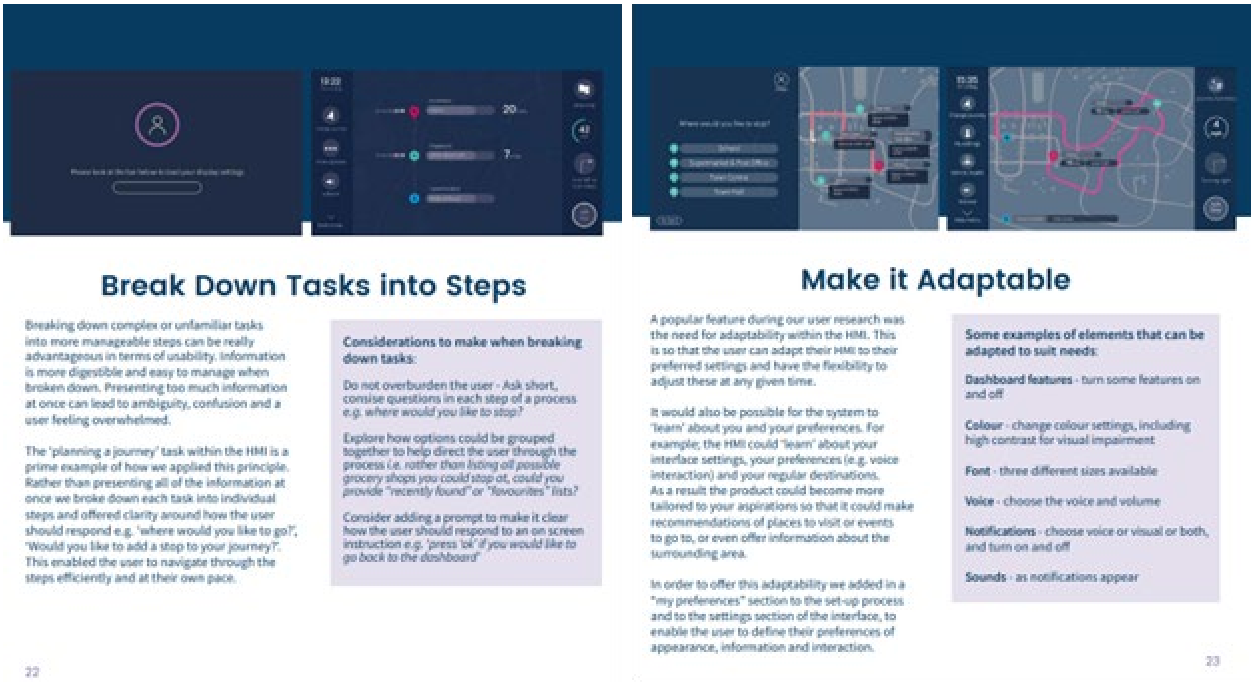
Figure 34. Accessible UI Design Guidelines 7 & 8 (Designability, 2019, p. 20,21).

- **Make it Intuitive**

Use familiar metaphors, clear icons, and straightforward wording so users can operate the system without extensive learning. Intuitive design enables immediate comprehension and faster adaptation (Designability, 2019).

- **Make it Approachable**

Minimize visual clutter and guide first-time users with simple onboarding, tutorials, or voice assistants. Gradual exposure to features lowers entry barriers and builds confidence (Designability, 2019).


Break Down Tasks into Steps

Breaking down complex or unfamiliar tasks into more manageable steps can be really advantageous in terms of usability. Information is more digestible and easy to manage when broken down. Presenting too much information at once can lead to ambiguity, confusion and a user feeling overwhelmed.

The 'planning a journey' task within the HMI is a prime example of how we applied this principle. Rather than presenting all of the information at once we broke down each task into individual steps and offered clarity around how the user should respond e.g. 'where would you like to go?', 'Would you like to add a stop to your journey?'. This enabled the user to navigate through the steps efficiently and at their own pace.

Considerations to make when breaking down tasks:

Do not overburden the user - Ask short, consise questions in each step of a process *e.g. where would you like to stop?*

Explore how options could be grouped together to help direct the user through the process i.e. *rather than listing all possible grocery shops you could stop at, could you provide "recently found" or "favourites" lists?*

Consider adding a prompt to make it clear how the user should respond to an on screen instruction *e.g. 'press 'ok' if you would like to go back to the dashboard'*

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Make it Adaptable

A popular feature during our user research was the need for adaptability within the HMI. This is so that the user can adapt their HMI to their preferred settings and have the flexibility to adjust these at any given time.

It would also be possible for the system to 'learn' about you and your preferences. For example; the HMI could 'learn' about your interface settings, your preferences (e.g. voice interaction) and your regular destinations. As a result the product could become more tailored to your aspirations so that it could make recommendations of places to visit or events to go to, or even offer information about the surrounding area.

In order to offer this adaptability we added in a "my preferences" section to the set-up process and to the settings section of the interface, to enable the user to define their preferences of appearance, information and interaction.

Some examples of elements that can be adapted to suit needs:

Dashboard features - turn some features on and off

Colour - change colour settings, including high contrast for visual impairment

Font - three different sizes available

Voice - choose the voice and volume

Notifications - choose voice or visual or both, and turn on and off

Sounds - as notifications appear

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Figure 35. Accessible UI Design Guidelines 9 & 10 (Designability, 2019).

- **Break Down Tasks into Steps**

Dividing complex processes into smaller steps prevents cognitive overload and builds self-efficacy. Step-by-step instructions (e.g., Choose start → Choose destination → Confirm trip) help users proceed with clarity and confidence (Designability, 2019).

- **Make it Approachable**

Personalization strengthens user comfort. Adaptive interfaces that remember preferences, such as font size, color contrast, or voice speed, create familiarity and reduce anxiety by making technology feel individually tailored (Designability, 2019).

2.4.10.1 Broader Strategies to Reduce Technology Anxiety

The ten Flourish principles go beyond HMI design by offering a psychological framework that tackles the core issues behind older adults' technology anxiety—cognitive overload, fear of failure, and loss of control (Designability, 2019).

- **Reducing Initial Cognitive Barriers: Clarity, Simplicity, and Intuitiveness:**

The most common source of anxiety for older adults facing new technologies is the overwhelming feeling of not knowing what to do. *Make it Attractive and Clear* and *Make it Intuitive* reduce cognitive load by emphasizing clear feedback, large fonts, and high contrast. These features help users interpret system states and quickly predict next steps. Similarly, *Balance Function with Simplicity* and *Make it Approachable* minimize visual clutter by layering features and providing step-by-step onboarding. Instead of showing all options at once, the system reveals information gradually, lowering intimidation and boosting psychological accessibility.

- **Alleviating Fear of Failure: Stepwise Tasks, Error Prevention, and Consistency:**

Older adults often hesitate to use technology due to fear of making irreversible mistakes. *Break Down Tasks into Steps* simplifies complex processes into manageable parts, giving users clear milestones and a sense of progress. *Anticipate User Error* reduces anxiety by offering straightforward recovery options, such as go-back buttons and confirmation screens, turning mistakes into manageable, non-threatening issues. Meanwhile, *Make it Consistent* creates predictable interaction patterns, allowing users to apply their previous knowledge across different screens. This consistency speeds up learning and builds user confidence.

- **Restoring Control and Building Trust: Flexibility, Adaptability, and Transparency:**

A significant part of technology anxiety comes from feeling a loss of control. Features such as *Make it Flexible* and *Make it Adaptable* address this by allowing users to customize settings, such as contrast, font size, or voice interaction modes, based on their preferences and sensory needs. Offering various interaction options, Such as touchscreen, buttons, and voice, helps strengthen the user's sense of control. Additionally, *Keep the User Informed* enhances transparency and predictability, which are essential for building trust. Providing real-time feedback, such as Obstacle detected and Slowing down, clarifies the system’s logic and decision-making process, turning an opaque automation into a reliable partner.

In conclusion, the ten principles outlined in the *Flourish Practice Report* go far beyond mere interface rules. Instead, they serve to create a comprehensive psychological framework that specifically addresses the most common and significant causes of technology anxiety experienced by older adults. These causes include cognitive overload, which can overwhelm users; a fear of making mistakes that discourages experimentation; and a reduced sense of control that diminishes confidence when interacting with digital tools.

By incorporating elements such as increased clarity, simplicity, flexibility, and transparency into the design of technology systems, designers can significantly transform how these systems are perceived and used. Rather than being seen as intimidating, complex, or frustrating, technology can be repositioned as a dependable, understandable, and empowering companion that supports older adults in their daily lives. This approach not only enhances usability but also fosters trust and confidence among users, ultimately encouraging more active, comfortable engagement with digital technologies.

2.5 Promote the use of Fully Autonomous Vehicles for Older People

2.5.1 Cognitive factors to engage the older people in FAVs

To increase acceptance of FAVs among older adults, social and emotional motivation strategies that go beyond technological perfection are essential. Research shows that while older adults see the potential benefits of FAVs, they emphasize that distrust in safety and fear of losing control over technology are key obstacles (Classen et al., 2021). Older passengers need social and emotional motivations beyond simple transportation. This approach is most effective when AVs are viewed as life-support services. This chapter suggests strategies focusing on cognitive design, physical accessibility, and community integration models.

2.5.1.1 Human-in-the-Loop Transition

During initial deployment, complete driverless systems may prompt psychological resistance among older adults. As a result, the ‘Human-in-the-Loop’ approach is crucial for fostering trust by combining technology with human oversight. Early mobility shuttle services typically include a Fleet Attendant or Autonomous Vehicle Operator (AVO) on board to help passengers board and disembark, assist with luggage, and oversee system functions (May Mobility, 2020). This operational strategy helps bridge the gap between ‘building trust in technology’ and the ‘actual riding experience’.

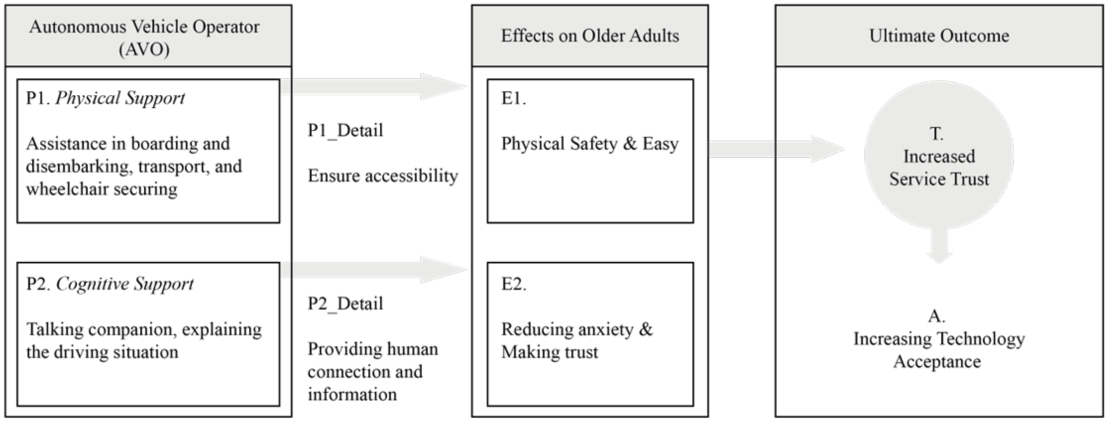


Figure 36. The Mechanism of Trust Building for Older People via AVO

2.5.1.2 Community-Integrated Service (MaaS) Model

AV services are more effective at reducing resistance and creating demand when they are integrated into community mobility infrastructure, like Mobility as a Service (MaaS), rather than serving solely as transportation methods. Successful adoption of AVs typically occurs when they address a community's specific needs. For instance, in Detroit, May Mobility collaborated with the Detroit Area Agency on Aging (DAAA) to launch the 'ACCESSIBILI-D' service, which caters to older adults and individuals with disabilities by providing essential trips such as hospital visits (U.S. Department of Transportation, 2024). This shows that the Community Integrated Maas Model is an effective way for older people to reduce resistance to FAVs, create demand, and achieve successful adoption.

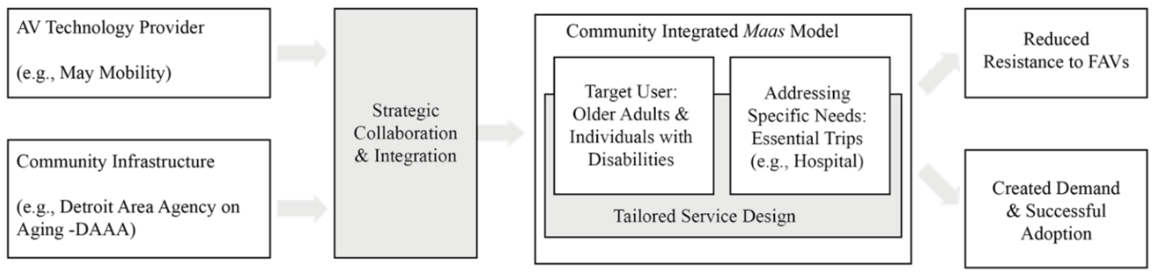


Figure 37. Community-Integrated Service (MaaS) Model.

One notable example is May Mobility's autonomous shuttle service, goMARTI, which has been running in Grand Rapids, Minnesota. Over 18 months, this project in a rural area with a challenging climate and an aging population utilized three autonomous wheelchair-accessible vehicles. It achieved a 91% return rate and a perfect 5-star user satisfaction score, highlighting not only the autonomous driving technology but also illustrating how "freedom of movement" can enhance the quality of life for older adults (May Mobility, 2023a).

2.5.1.3 Redefining as Social Mobility

Research shows that older adults tend to have more positive attitudes and are more open to accepting AVs when they use them with friends or family for leisure activities, such as tourism or social gatherings, rather than alone (Fan & Pan, 2025). Implementing shuttle-type AVs in retirement communities—such as The Villages in the U.S. or Marian Grove in Australia—and allowing neighbors to go grocery shopping or visit community centers together can foster 'Social Proof' (Swift Navigation, n.d.). Seeing peers or community members confidently use AVs and participate in social activities can significantly lower initial resistance.

2.5.2 Physical Factors to Engage Older People in FAVs

The vehicle's physical design removes barriers to entry that hinder use. For wheelchair users or older people with limited mobility, boarding can be a major challenge. To successfully accommodate older passengers with FAVs, these physical obstacles need to be addressed.

2.5.2.1 Physically Tailored Design for Older Users

AVs converted from existing Internal Combustion Engine (ICE) vehicles often face challenges with wheelchair access. For older passengers and those with mobility issues, including wheelchair users, AVs need to be designed with accessibility in mind from the start. On the other hand, Purpose-Built Vehicles (PBVs) such as Zoox, Cruise Origin, and May Mobility have prioritized inclusivity from the beginning. These vehicles feature low-floor layouts, ramps, and carriage-style seating, making them more accessible for older people and reducing physical barriers (Cruise LLC, 2024; Zoox, 2025). Therefore, to effectively build trust and foster a positive attitude towards FAVs, it is essential to improve accessibility to these technologies by removing barriers and ensuring equal opportunities for all users, which is crucial for achieving widespread acceptance and confidence in FAVs.

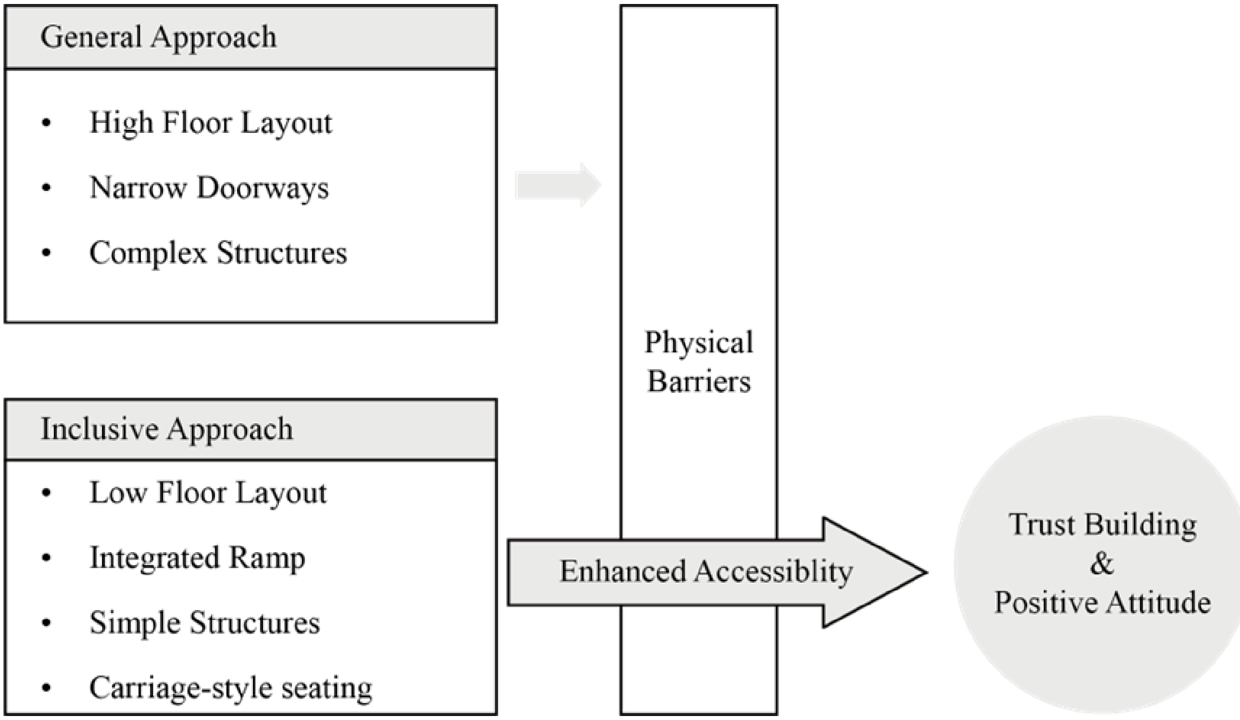


Figure 38. Physically Tailored Design for Older People

2.5.2.2 Digital HMI (Human-Machine Interface) Design for Trust Building

For older adults, autonomous vehicles are more than just technological innovations; they are essential tools for aging with dignity and maintaining independence. Building trust in technology and fostering positive attitudes can be achieved through 'experience' and 'education.' This means that applications and in-vehicle interfaces must be intuitive and deliver a positive user experience. Achieving this requires accessible design and straightforward communication. To earn the trust of older users, digital HMIs should be designed to be simple, consistent, accessible, and clear (Fraade-Blanar et al., 2021).

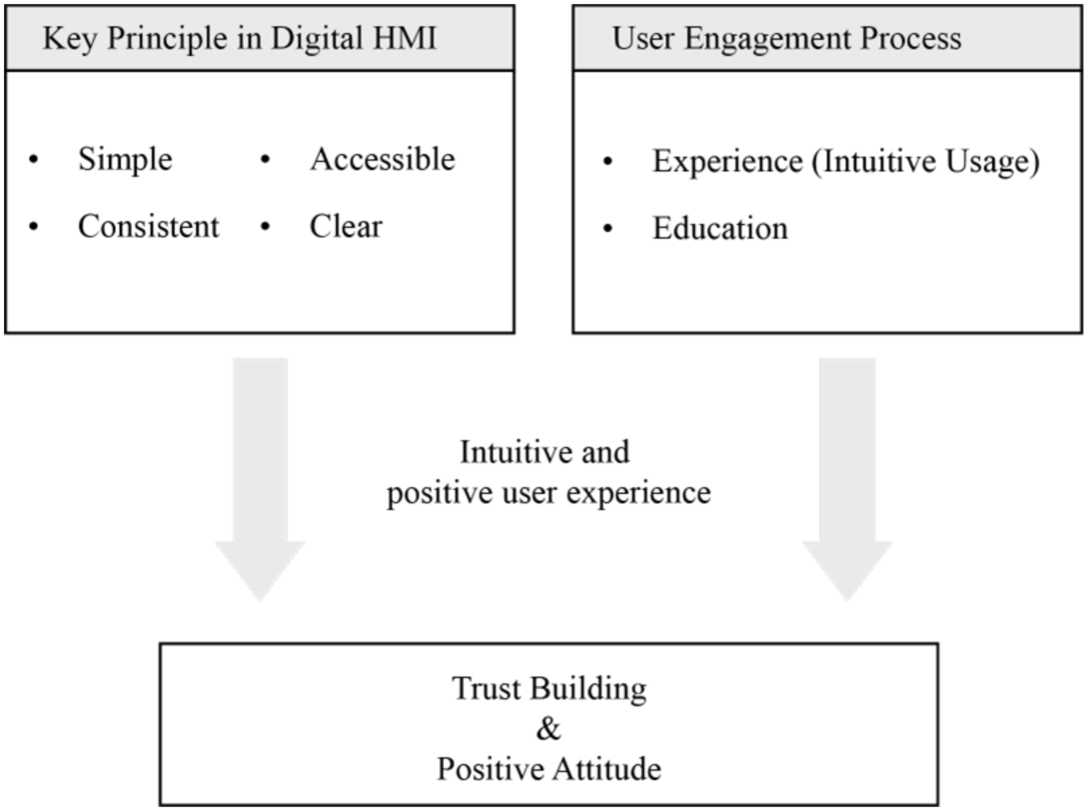


Figure 39. Digital HMI (Human-Machine Interface) Design for Trust Building

2.6 Conclusion

This chapter reviewed essential theoretical backgrounds and design principles to establish comprehensive FAV design guidelines for older people. The concepts examined are interconnected, forming a cohesive theoretical foundation for this study by creating a mutually supportive relationship that ranges from understanding user characteristics to practical design implementation strategies.

Encouraging older people to adopt FAVs requires not only addressing technological challenges but also designing human-centered services and overcoming psychological barriers. Future studies should conduct empirical research to determine if these strategies lead to sustained use, higher satisfaction, and reduced social isolation among real older populations.

Furthermore, as technology advances, it is crucial to examine how older adults' acceptance of new HMI features, such as remote support, telemedicine, and emotional interaction, changes as these features are introduced. In conclusion, increasing acceptance of FAVs among older adults requires a design that considers social, emotional, cognitive, and physical factors alongside technological innovation. This comprehensive approach helps make FAVs inclusive mobility solutions that not only provide transportation but also improve the overall quality of life for older people.

Therefore, the FAV design guidelines proposed in this study should aim to integrate human-centered 'Usability' and emotional 'Inclusivity' while emphasizing 'Accessibility' to address the physical, cognitive, and emotional limitations of older people. The principles discussed above will be utilized as criteria for developing concrete design guidelines that ensure not only the physical safety of older users but also their psychological well-being and independence in the subsequent case analysis in Chapter 3 and the guideline proposal provided in Chapter 4.

Chapter 3 Case Studies - Current FAVs and Service Design

3.1 Case Study Overview

This chapter aims to analyze how inclusive design principles identified in the literature are implemented in commercialized FAV systems. To achieve this, the study employs a case study methodology based on publicly available data. This approach enables a critical examination of both the achievements and the limitations of current technologies, providing a foundation for the design guidelines developed in Chapter 4.

By examining existing products, it is possible to determine which design features effectively support older people and wheelchair users. This analysis allows designers to understand how to specifically reflect users' needs and identify useful functions and areas for improvement. Moreover, by analyzing how various functions are applied to each product, designers can identify practical design elements and problems (Riggs & Pande, 2021).

3.2 Existing Current FAVs Case Study

This case study investigates the extent to which commercially available or recently introduced FAVs fulfill the needs of older people and people with disability. The vehicles examined include the Olli 2.0, Zoox, Cruise WAV, May Mobility, and Renault EZ-GO.

Each case is scrutinized utilizing the 'FAV Evaluation Framework' formulated in this research, comprising three dimensions: features, interior design, and key insights. The framework is not a descriptive tool but was developed by synthesizing key theoretical insights from the literature review in Chapter 2:

Universal Design Principles: To evaluate the equitable use and flexibility of the vehicle interface.

Inclusive Design & Affordance: To ensure the design addresses the specific exclusion points faced by older people.

Aging in Place & Human Factors: To assess how the physical and cognitive changes of aging are accommodated within the vehicle environment.

This methodology enables designers to precisely understand how to incorporate user requirements and identify advantageous functions as well as areas that require improvement. Additionally, by examining the application of various functionalities across different products, effective design elements and potential issues can be identified.

3.2.1 Olli 2.0

Local Motors' Olli 2.0 is an autonomous electric shuttle manufactured using 3D printing technology. The vehicle has a box-shaped design with central double-wide doors. Developed through technical collaboration with LM Industries and Robotic Research, this vehicle is designed to provide sustainable, accessible transportation solutions in specific areas such as university campuses or urban environments (IVO Media, 2019; Musulin, 2020).

Figure 40. Olli FVA(IVO Media, 2019)

3.2.1.1 Features

One of the key features of Olli 2.0 is its high utilization of additive manufacturing, or 3D printing technology. Approximately 80% of the vehicle is made from recyclable 3D-printed materials, and this process allows the vehicle's basic structure to be completed in just 9 hours. This maximizes production efficiency by enabling the vehicle to be assembled with 90% fewer parts than traditional vehicles (IVO Media, 2019).

Additionally, a high level of customization is possible. Augmented reality (AR) and virtual reality (VR) features can be added based on user needs, and the interior design can also be freely customized. For example, the vehicle can be configured to optimize specific purposes, such as reducing the number of seats and securing space for patient beds to suit a hospital environment (Korosec, 2019; Watkin, 2019).

Another major feature is user interaction through anthropomorphism. Olli 2.0 features an eye-shaped screen on the front and an external PA (Public Address) system that can communicate with pedestrians. This design helps lower psychological barriers to autonomous shuttles and builds trust with both passengers and pedestrians (Korosec, 2019).

Figure 41. Olli 2.0 Front view (Korosec, 2019).

3.2.1.2 Interior

The Olli 2.0 features a large central touchscreen that allows passengers to access routes, media, and information. For voice interaction, it is equipped with an enhanced speaker and microphone system powered by IBM Watson and Amazon Lex, enabling natural language conversations and guidance in various languages, including Korean. The vehicle's interior, including seats, lighting, and design, can be customized for different purposes. Safety is addressed with an emergency stop button and a remote control system, while high-resolution displays and audio equipment provide clear voice guidance both inside and outside the vehicle (Korosec, 2019; Martial, 2019).

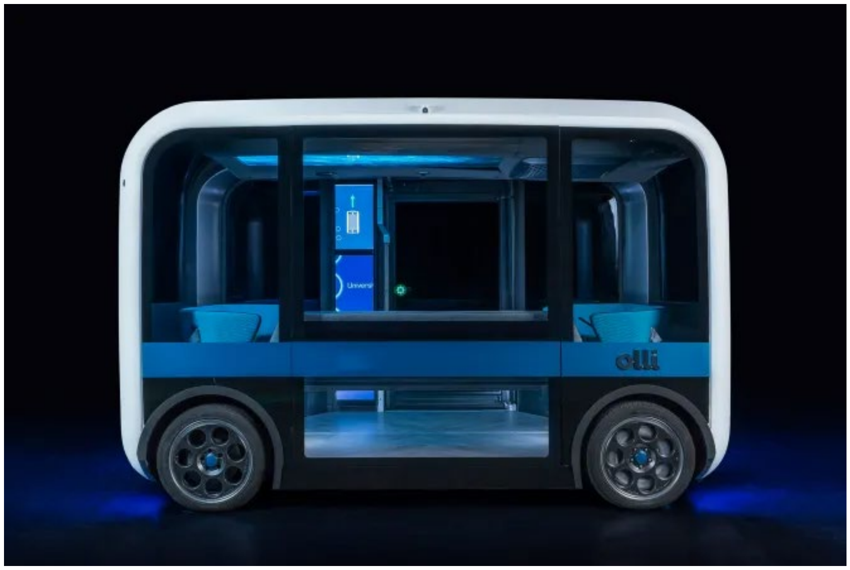


Figure 42. Side view (Korosec, 2019).

Figure 43. Inside seat and display (Korosec, 2019).

3.2.1.3 Key Insights

Olli 2.0 demonstrates the future direction of autonomous vehicles through its human-centric interface and customizable design, while simultaneously re-emphasizing the importance of physical accessibility.

Building Trust Through Emotional Connection: Olli 2.0's most significant feature is its anthropomorphic interface, which facilitates communication with users. This goes beyond simply conveying information to form an emotional bond between the machine and the user. This approach can be highly effective in lowering psychological barriers for older users toward new technologies and building trust in the vehicle.

Flexible Custom Design and Sustainability: The ability to custom-manufacture interior components such as seats, handrails, and wheelchair restraints using 3D printing technology is a significant advantage. This demonstrates the potential to accommodate older users with diverse physical conditions and is also meaningful from a sustainable production perspective.

Disadvantage: Regarding accessibility, there are noticeable limitations. While it is noted that the vehicle features an ADA-compliant manual ramp (RideBeep, n.d.), there is insufficient detail on how the ramp operates or whether wheelchair users can board and secure themselves independently.

3.2.2 Zoox

Zoox is an electric autonomous vehicle designed for an urban robotaxi service by an autonomous driving startup acquired by Amazon in 2020. It operates in San Francisco and Las Vegas. It features a salmon-style bidirectional design, allowing it to easily change direction or make U-turns on narrow roads and move in the desired direction on curved paths. Equipped with a four-wheel steering system, it can travel in any direction, making it easy to park. Additionally, it can reach speeds of up to 60 mph (approx. 96 km/h) and operate for up to 16 hours on a single charge (Reineke, 2020).

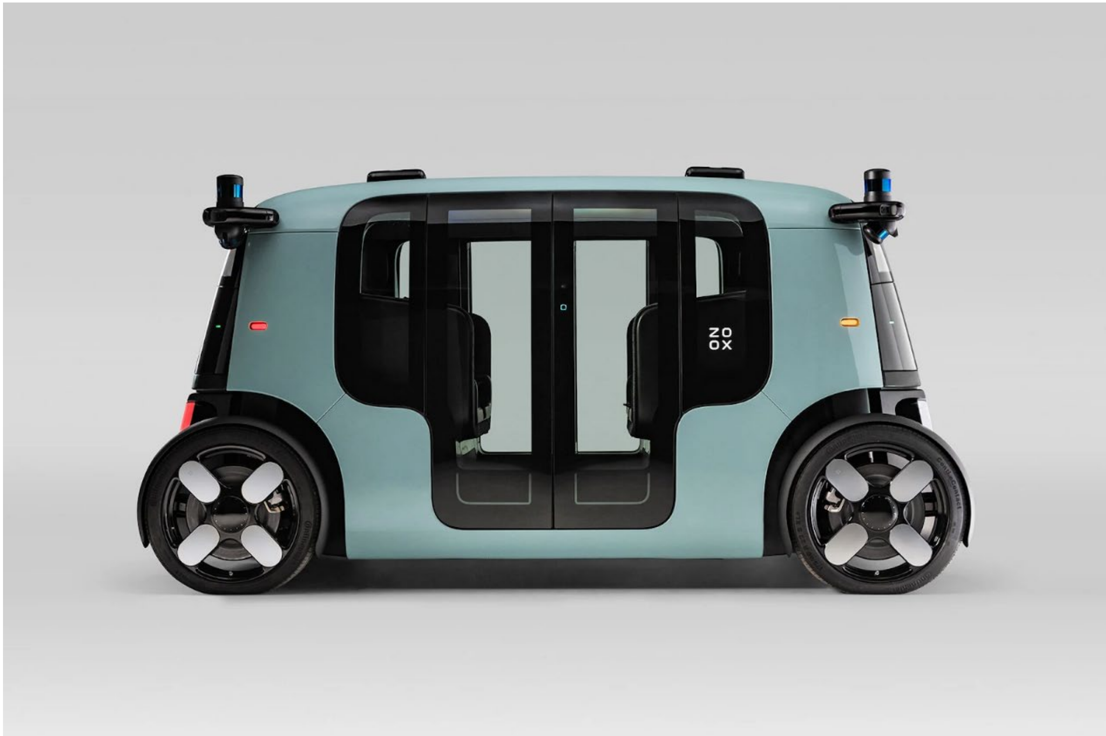


Figure 44. Zoox (Reineke, 2020).

3.2.2.1 Features

All seats are fully equipped with seatbelts and airbag systems. In particular, the front seats feature a unique U-shaped airbag that mitigates impact from all directions, providing comprehensive protection including frontal, rear, side, and rotational collisions, regardless of the vehicle's direction of travel (refer to Fig. 45).

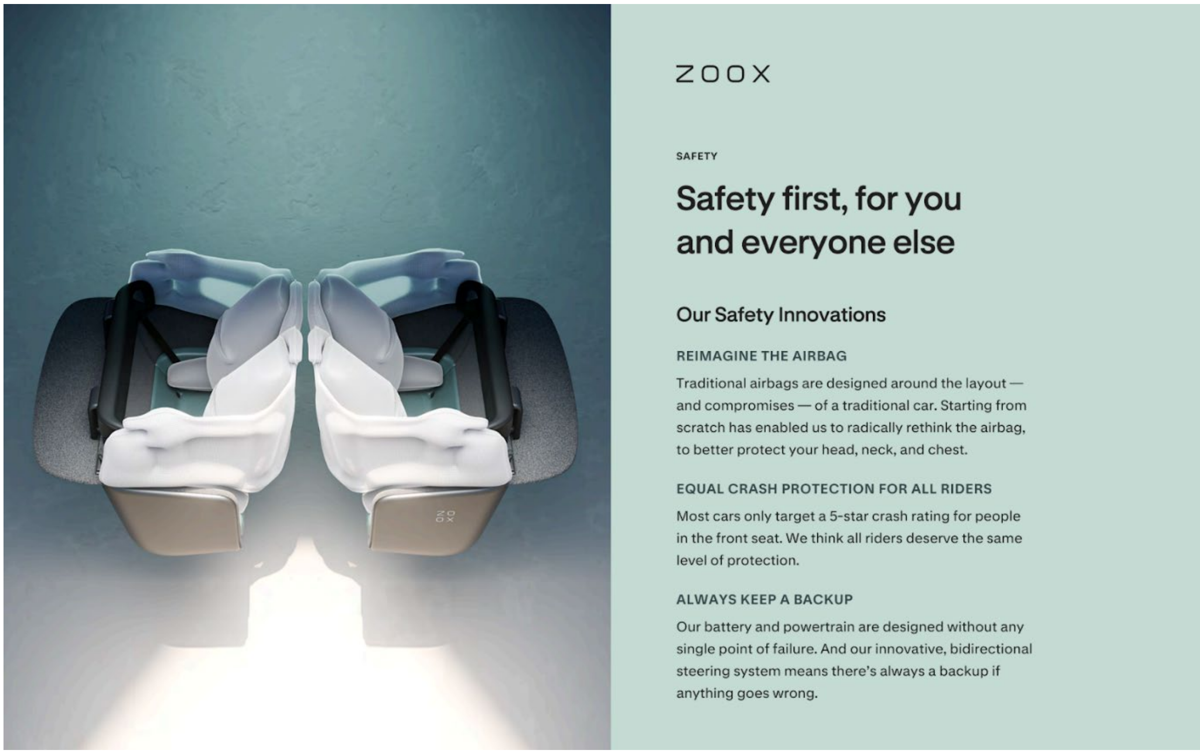


Figure 45. Air bag (Zoox, 2025, p. 9).

Additionally, an emergency button is easily accessible to passengers for quick use. Additionally, the emergency door release button next to the seat allows passengers to exit quickly and easily in an emergency or when the battery is out (refer to Fig. 46)

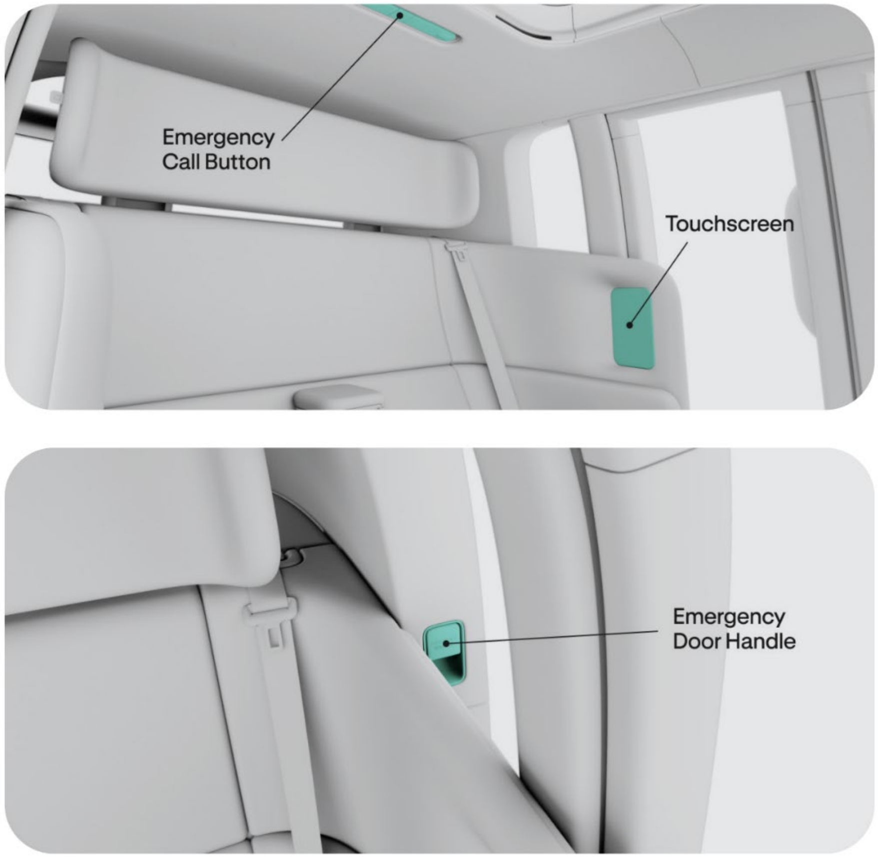


Figure 46. Zoox Emergency Buttons (Zoox, 2025)

3.2.2.2 Interior

Zoox's interior has no driver's seat, with four seats arranged face-to-face for four passengers. There are no partitions between the two rows of seats, making the interior open, and the entire glass surface acts as a window, allowing passengers to see their surroundings clearly (Reineke, 2020). Between each row of seats are cup holders and wireless phone chargers (refer to Fig. 47)

Figure 47. Cup holder and wireless phone charger.

To use Zoox, users request a ride through a smartphone app and receive real-time driving routes and destinations on the in-vehicle display upon boarding. Passengers do not need to manually enter destinations, as Google Maps-based destination settings are available, and friendly passenger guidance is provided via voice prompts. There is a total of four touchscreens located next to each seat, offering various functions such as opening/closing doors, displaying distance to the destination and remaining time, travel time, internal temperature control, and media playback (refer to Fig. 48)

Figure 48. Seat and Control Interface (Reineke, 2020)

3.2.2.3 Key Insights

While the Zoox vehicle makes a commendable effort to build psychological comfort through technology, it also clearly highlights areas needing improvement to enhance convenience for all users, including older people.

Ensuring Safety Through Proactive Design: Providing real-time driving information on both interior and exterior displays, combined with easily accessible call buttons and touchscreen menus, helps reduce user anxiety about potential malfunctions and fosters a sense of psychological stability.

Disadvantage: The reliance on touchscreens and smartphones for vehicle reservations can be unintuitive and challenging for older users unfamiliar with digital devices. Usability could be greatly enhanced by providing more intuitive and familiar solutions, such as an in-cabin emergency bell and call buttons. Furthermore, the current design lacks direct physical accommodations for wheelchair users, such as dedicated spaces or a ramp. This is a critical area that must be addressed for the solution to become truly inclusive.

3.2.4 Synthesis

The case studies of Olli 2.0 and Zoox demonstrate the potential of current autonomous vehicle technology to solve mobility issues for older users, while also clearly showing that there is still a long way to go to meet their practical needs.

Both vehicles attempt to build the core value of 'trust' in different ways. Olli 2.0 focuses on building an emotional connection through an anthropomorphic interface, while Zoox aims to ensure technological stability by delivering clear information through internal and external displays. These approaches suggest two important design directions for future autonomous vehicles to gain user trust.

However, both cases revealed significant limitations in terms of physical 'accessibility'. The lack of space for wheelchair users and the difficulty of using ramp structures indicate that technological innovation alone cannot encompass all users. Furthermore, an overreliance on new interfaces, such as touchscreens, can be another barrier for older users unfamiliar with digital devices.

In conclusion, despite technological advancements, current autonomous vehicles are still in the early stages of inclusive design for older users. The limitations revealed by this case study's analysis provide specific directions for the design guidelines needed to achieve true mobility freedom for older users.

3.3 Inclusive FAVs Case Study

It is crucial to analyze fully inclusive autonomous vehicles (FAVs) to understand their applicability for older users and wheelchair users. This case study reviews several products, focusing on their design features and functions. The analysis highlights which elements effectively address the needs of these user groups and which aspects require improvement.

Each case is analyzed using the "Inclusive FAV Evaluation Framework" developed in this study, consisting of three dimensions: accessibility features, interior design, and key insights. This systematic analysis enables an evaluation of how effectively each case addresses the physical, cognitive, and psychological needs of older users.

3.3.1. Cruise Wheelchair Accessible Vehicle (WAV)

The Cruise Wheelchair Accessible Vehicle (WAV) is a purpose-built autonomous vehicle developed jointly by General Motors and Cruise, based on the Cruise Origin platform. It represents a fundamental rethinking of vehicle architecture, as it is a fully autonomous shuttle completely devoid of traditional driving controls such as a steering wheel or pedals. The vehicle features a distinctive boxy design that maximizes interior volume and a completely flat, low-floor structure. The dimensions of the parent Origin platform are approximately 15 feet (4.6 meters) in length, 6.5 feet (2 meters) in width, and 6.5 feet (2 meters) in height, providing a spacious interior comparable to that of a mid-to-large SUV. The WAV's structure has been specifically engineered for wheelchair users and optimized for shared urban mobility services (Cruise LLC, 2024; Hawkins, 2023).

cruise

Section One: The Cruise Origin Autonomous Vehicle

Image of a Cruise Origin self-driving, all-electric vehicle

Cruise Origins use a fully integrated self-driving system incorporated into our purpose-built Origin vehicle, developed in partnership with General Motors (GM) and Honda, and manufactured by GM. The Cruise Origin is engineered to operate safely on its own – with no driver – within a defined operating environment and under a specific set of conditions. More information about those parameters can be found in the Operational Design Domain (ODD) section of this guide.

Cruise's self-driving system is integrated into the Origin through close coordination between the hardware and software teams at both GM and Cruise.

Identifying the Cruise Origin

Each Cruise Origin will have distinguishing features – including four external displays on the corners of the vehicle that can display characters, symbols, and other information – which users and law enforcement can use to identify vehicles in addition to the distinct alpha numeric combination displayed on each vehicle's license plate. The vehicle is approximately 15 feet long and 6.5 feet tall and wide, the size of a mid- to large-size SUV.

Figure 49. Identifying the Cruise Origin *(Cruise LLC, 2024)*

3.3.1.1 Accessibility Features

The Cruise WAV integrates a suite of accessibility features designed to facilitate autonomous boarding and alighting for older users and individuals in wheelchairs. The vehicle is equipped with double-wide doors that provide a generous opening. Upon arrival, a "kneeling" function automatically lowers the vehicle's body to align its floor with the curb height. Simultaneously, an integrated, automated folding ramp deploys to bridge the gap, enabling safe, smooth entry. For enhanced safety and visibility, the ramp is flanked by LED warning lights and features raised edges to prevent wheels from slipping off the sides. This helps ensure visibility and safety for wheelchair users (Hawkins, 2023).

Figure 50. Double-Wide Doors and Ramp (Hawkins, 2023).

The wheelchair securement system, which is directly linked to user safety inside the vehicle, is offered in two complementary methods.

1. **Q'Straint's wheelchair docking system** automatically engages with compatible power wheelchairs, allowing the wheelchair user to easily secure the wheelchair themselves. Currently, it is only compatible with wheelchairs of certain brands, including Permobil M-Series, Quantum Q6 Edge, and SM Quickie Q500/700M/Q7 wheelchairs (Refer to Fig. 51).
2. **For manual wheelchairs or incompatible models**, manual fixation is possible using a strap-and-hook system shared by a passenger. However, manual strapping offers wider compatibility but often requires assistance from a

companion, potentially undermining the core value of autonomous vehicles: independent mobility (Refer to fig. 52)

This dual approach reflects an effort to accommodate users with varying levels of independence and a variety of mobility devices. Providing these different anchoring methods can offer a safer, more convenient option for a wider range of wheelchair users (Hawkins, 2023; Self Drive News, 2023).

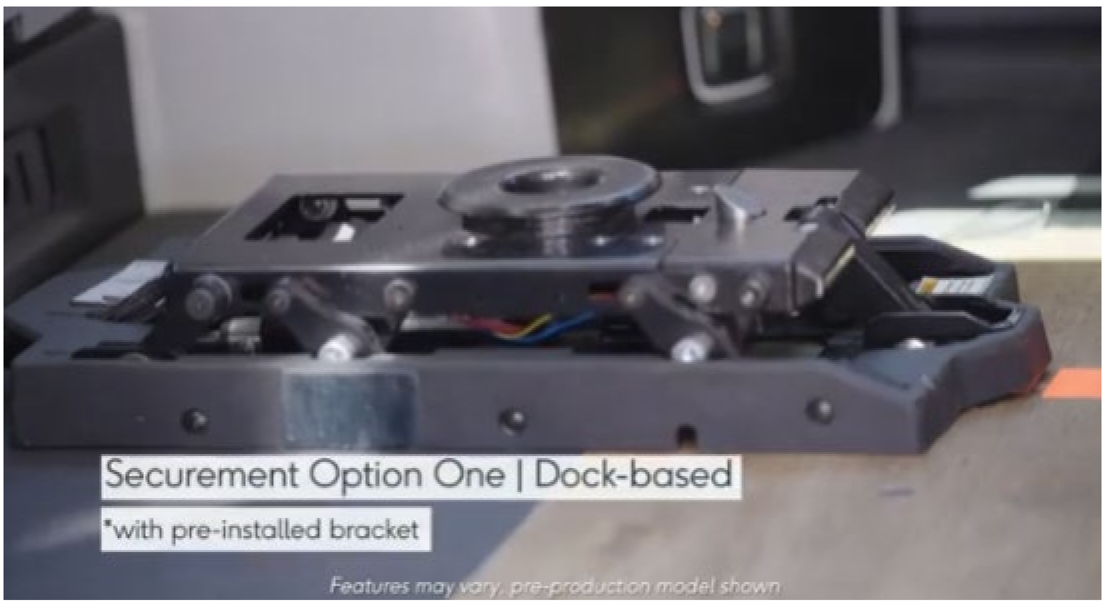


Figure 51. Securement Option One: ‘Dock-based’ with pre-installed bracket (Kvogt, 2023).

Figure 52. Securement Option Two: ‘Strap-based’ assistance is required (Kvogt, 2023)

3.3.1.2 Interior

The interior of the Cruise WAV is designed to maximize usable space and ergonomic comfort for all passengers, especially those with mobility needs. While the standard Origin model seats four passengers face-to-face, the WAV is designed to accommodate one wheelchair user and two non-wheelchair passengers (Hawkins, 2023; Migliore, 2020). This spacious layout is enabled by the low floor and high ceiling, which help facilitate easy movement within the vehicle. Strategically placed grab handles are on both sides of the entrance to support ambulatory users with mobility challenges during entry and exit.

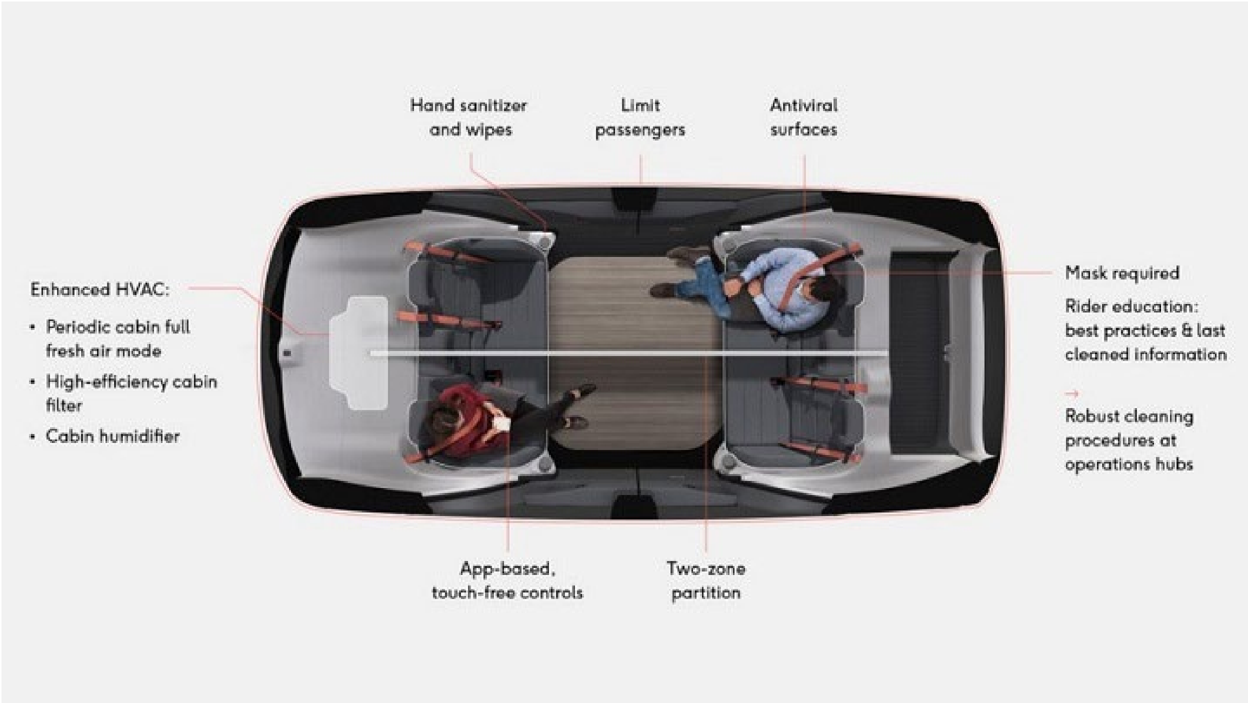


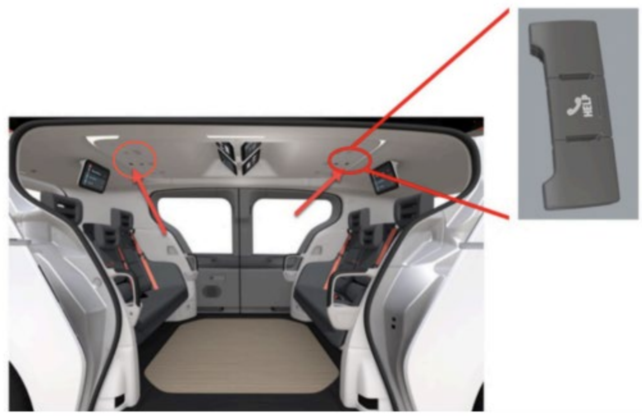
Figure 53. Top-Down View of the Cruise Origin Interior Layout (Migliore, 2020)

Figure 54. Cruise WAV's Interior Space and Fold-Down Seating Arrangement (Hawkins, 2023).

Figure 55. Use of the Internal Interface by Wheelchair Users (Hawkins, 2023).

Cruise WAV incorporates a multi-modal user interface. The user experience is mediated through a sophisticated system of in-vehicle displays and information systems designed to build trust in the autonomous system. The vehicle is equipped with a total of six displays, including four large central screens and two screens located above each seat. These provide real-time journey information, route progress, and system status updates (Cruise LLC, 2024).

cruise



Location of customer-accessible 'Help' buttons facing each set of seats in the Cruise Origin

When police officers and first responders call the Cruise critical response line, they will be connected with Cruise team members who are specially trained to assist with issues related to the vehicle in non-emergency and emergency situations. For example, this team can provide information about unlocking the vehicle, confirm operating status, disengage the Cruise Origin from autonomous driving mode and ensure that it remains in a safe, stationary position. These Cruise team members are also trained to communicate with passengers and third parties during emergency situations.

Law enforcement and first responders can contact Cruise Remote Assistance Advisors by calling Cruise's critical response line: **888-662-7103**

Figure 56. Inside the Cruise Origin (Cruise LLC, 2024)

Besides digital interfaces, physical buttons and switches are carefully positioned inside the cabin. These enable passengers to control essential functions, such as locking or unlocking the wheelchair dock, starting or stopping the ride, operating the doors, and deploying or retracting the ramp. An emergency button is also clearly accessible for immediate help. This multi-modal interface lets users interact with the vehicle through physical controls, onboard displays, or a smartphone app, accommodating various user preferences and levels of technical familiarity (Watanabe, 2023) (refer to Fig. 57).

Figure 57. Control buttons in WAV (Kvogt, 2023).

3.3.1.3 Key Insights

The Cruise WAV demonstrates how a purpose-built design can integrate accessibility as a core component. Several elements offer critical lessons for inclusive FAV design.

Wheelchair-Centric Redesign: Cruise WAV shows how a future shared autonomous vehicle can be redesigned specifically for wheelchair users. Features such as an automatic ramp, a kneeling low-floor, and a wide doorway enable entirely independent boarding without assistance. This indicates that design tools for FAVs should modularize components such as entrance width, ramp angle, and automatic chassis lowering to serve diverse user needs.

Dual Securement Methods: Offering both docking and strap-based securement systems provides flexibility across different wheelchair models. An innovative design tool might allow users to enter their wheelchair specifications and automatically suggest the most suitable securement method.

Multi-Interface: Using external displays, internal voice guidance, and tactile buttons together addresses diverse sensory needs. Design guidelines should include "simultaneous audio-visual feedback," clear iconography, and strategic placement of emergency-call buttons to ensure information is accessible to all passengers.

Modular Seating and Companion Space: The WAV’s seating is adaptable and includes space for a caregiver or assistant. Design tools might include options for companion seats or removable seats, recognizing that some wheelchair users travel with companions.

Disadvantages: The dual security system creates an inequity; users with compatible, modern electric wheelchairs experience seamless automation, while others must rely on a manual system that requires assistance. This tiered accessibility violates the Principle of Equitable Use. Furthermore, the presence of six interior displays poses a risk of cognitive overload for some older users, potentially inducing stress rather than building trust.

3.3.2 May Mobility Accessible AV (Murphy)

Established in 2017, May Mobility is a company specializing in autonomous vehicles, headquartered in Ann Arbor, Michigan. The organization focuses on deploying shuttle services in urban environments. Their accessible vehicle, designated as "Murphy," is a compact, low-speed electric shuttle constructed on the Polaris GEM e6 platform. This vehicle exemplifies evolutionary design, refined by insights from preceding models. Murphy exhibits a symmetrical, curved silhouette, rendering it bidirectional. It is engineered for boarding from both sides and features a central display section accessible from either side (May Mobility, 2019; 2020).

Figure 58. Murphy (May Mobility, 2020).

3.3.2.1 Accessibility Features

Based on valuable feedback from wheelchair users, Murphy utilizes a fully automatic folding ramp for wheelchair users, with raised fall-prevention edges on both sides to prevent the wheels from sliding sideways. Wheelchair securing is achieved using a manual harness system that attaches straps to the wheelchair's front and back.

Unlike Cruise's fully automated approach, May Mobility's model relies on a "human-in-the-loop" system supported by an Autonomous Vehicle Operator (AVO). The

AVO is present to assist with boarding and alerting, controlling the ramp, securing equipment, and performing safety checks. This human oversight is a core element of their current service model. Wheelchair securement is achieved using a manual harness system, with straps attached to the wheelchair's front and rear. This method is designed to be versatile, supporting a wide variety of wheelchair types, and is crash-tested to ensure passenger safety (May Mobility, 2020).

3.3.2.2 Interior

The interior configuration is segmented, with one section occupied by passenger seats and the opposite section featuring a spacious, open area designed to accommodate a wheelchair user. This adaptable layout also ensures sufficient space for a service animal to accompany a passenger. May Mobility has also emphasized the importance of providing clear, multi-modal information to passengers, especially those with sensory impairments. The interior of the Murphy vehicle is equipped with speakers and a large visual display panel that collaboratively delivers essential journey information. This system offers real-time updates on boarding and alighting cues (e.g., arrivals/departures, doors opening/closing), route progress, upcoming stops, and safety protocol announcements. Displays are designed with a 49" large curved shape, and these curved touchscreens and forward-facing seats are designed to engage passengers with the interface. Information is presented with large, easy-to-read text and intuitive icons on the screen, while simultaneous audio announcements serve passengers with visual impairments. This synchronized audio-visual feedback system is a direct application of the Universal Design principle of Perceptible Information (May Mobility, 2019).

Figure 59. Interior of Myla 2.0 curved touchscreen (May Mobility, 2019).

Figure 60. Interior concept of Myla 2.0 showing curved touchscreen and facing seat configuration (May Mobility, 2019).

3.3.2.3 Key Insights

Flexible Interior Configuration: Murphy accommodates one wheelchair and two other passengers, with additional space for a service animal. Its symmetric front/back boarding design and blocked center mean it can be configured for different passenger mixes (e.g., turning some seats around or creating open space as needed). This highlights the value of flexible seating layouts in design.

Human Operator Requirement: The use of an AVO for ramp control and securement is a critical factor. It shows that, at current technology levels, human assistance is needed for safe boarding. Any design guideline should therefore consider options for a phased autonomy model in which a human aide or caregiver is available, rather than assuming full autonomy immediately.

Multi-Sensory Information: Providing both visual displays and voice announcements ensures accessibility to users with visual or hearing impairments. Design tools should include modules for combined audio-visual feedback (e.g., co-located screens and speakers), clear iconography and text guidelines, and controls to adjust voice volume and speed to meet various sensory needs.

Disadvantages: Because Murphy depends on an AVO for critical tasks, it cannot fully board passengers independently. It is not a scalable model and undermines the "fully autonomous" vision by negating the long-term economic benefits of autonomy. Its layout (blocked center, end boarding only) may restrict flow when handling higher passenger volumes. The harness system, while adaptable, may still require custom adjustments for some wheelchair models.

3.3.3 Renault EZ-GO

Renault EZ-GO is an electric, autonomous, shared "robo-vehicle" concept first revealed at the 2018 Geneva Motor Show. Its approximate dimensions are 204.7 inches long, 86.6 inches wide, and 63.0 inches tall (with the rear hatch closed), with a 149.6-inch wheelbase; it weighs about 3747 pounds, including the batteries. The vehicle features a panoramic glass roof to let in natural light. Renault describes the EZ-GO as offering an unprecedented 360° open window on the city, providing passengers with a friendly space to relax and enjoy the ride (Wendler, 2018).

Figure 61. Renault EZ-GO Concept image (Kriveviski, 2018).

3.3.3.1 Accessibility Features

The EZ-GO's most innovative accessibility feature is its unique front-entry mechanism. Instead of side doors, a large portion of the vehicle's front, including the windshield, lifts like a hatch. As the hatch opens, a small platform integrated into the vehicle's floor lowers to become a ramp, creating a seamless, level entry directly from the curb. This design solves the challenge of sidewalk alignment for side-loading vehicles. To enhance safety, ground lighting projects onto the pavement to clearly indicate where the ramp will land. The vehicle's low entry height and completely flat interior floor are designed to accommodate wheelchair users with minimal effort (Kriveviski, 2018).

Figure 62. Renault EZ-GO Concept image of the rear hatch open (Kriveviski, 2018).

3.3.3.2 Interior

The interior features a U-shaped seat layout that encourages social interaction while maximizing space. Inside the vehicle, there are handles on both sides that separate the storage space from the seats, helping users get on and off. The seats have no partitions between them, creating an open, lounge-like space. Additionally, inductive charging for personal devices is built in for passenger convenience. A large screen displays trip information, and interaction is primarily handled through the passenger's smartphone, which connects to the vehicle's systems (Wendler, 2018).

Figure 63. Renault EZ-GO interior (Kriveviski, 2018)

3.3.3.3 Key Insights

As a concept vehicle, the EZ-GO reimagines vehicle access from the ground up. The front-entry ramp is an innovative solution that provides excellent accessibility from the sidewalk. The spacious, sociable interior design creates a welcoming environment that differs significantly from traditional transportation.

Inclusive Entry Design: EZ-GO emphasizes a low-floor, ramp-entry design with clear visual cues, showing how a vehicle can enable easy boarding for wheelchair users. The use of floor lighting to mark the boarding point is a helpful guidance feature.

Social Interior Space: The U-shaped lounge seating creates a comfortable, social environment, suggesting that autonomous shuttles can focus on passenger experience beyond mere transit.

Disadvantages: Besides the missing wheelchair-securement detail, EZ-GO is only a prototype concept. The large, upward-opening door and automatic ramp mechanism could face reliability and safety challenges in adverse weather conditions or on uneven surfaces. The focus on open design may also overlook factors like climate control and user privacy. Also, the purely digital interface may pose a barrier for individuals who are not comfortable with smartphone apps, particularly older adults. Finally, the available concept documentation omits any detail on how wheelchairs would be secured inside the vehicle. Without a clear wheelchair restraint method, it is unclear how the design ensures safety for wheelchair passengers during travel.

3.3.4 Synthesis

Every case study showcases a distinct approach, but a comparison allows identification of key patterns and trade-offs that are crucial for creating design guidelines.

The distinct perspectives of Cruise WAV, May Mobility's Murphy, and Renault EZ-GO concepts offer a comprehensive view of the current design landscape. Overall, Cruise WAV aims for fully automated, independent accessibility, while May Mobility's Murphy presents a practical model that ensures reliability through human support within current technological limitations. Renault EZ-GO shows the potential to revolutionize vehicle access itself through a forward-looking concept, but it lacks concrete solutions to specific safety issues.

These cases illustrate the significant potential of fully autonomous driving technology to dramatically improve mobility for older adults and wheelchair users, while also revealing an imbalance between technological advancement and inclusivity in current fully autonomous shuttles, underscoring the need for design guidelines to address this gap.

The table below refines and compares the key characteristics of the analyzed vehicles, providing a clear, at-a-glance summary of their features. This table shows that each case has attempted to implement inclusivity and accessibility in autonomous shuttle design, but each has certain limitations.

Table 2. Comparative Framework of Accessible FAVs

Features (Application of Inclusive Design Principles Feature)	**Cruise WAV**	**May Mobility Murphy**	**Renault EZ-GO**
Vehicle Type	Modified Commercial EV	Purpose-Built Shuttle & Modified Minivan	Purpose-Built Concept Vehicle
Ramp/Access (Inclusion & Accessibility)	Double-wide automatic doors and a kneeling function with an automatic folding ramp	Manual/assisted ramp (controlled by AVO)	Front-opening glass canopy door with automatic boarding ramp
Door (Accessibility)	wide-opening automatic doors	Both-sided opening automatic doors	Upward-opening automatic door
Seating Configuration (Ergonomics & Capasity)	Open layout with adaptable seats 2passenger, 1Wheelchair	Forward-seat + open wheelchair area 2passenger, 1Wheelchair	U-shaped lounge arrangement 6 passengers, 1Wheelchair

Features (Application of Inclusive Design Principles Feature)	**Cruise WAV**	**May Mobility Murphy**	**Renault EZ-GO**
User Interface/ Interaction (UI/UX & Interaction)	Physical buttons, display, voice guidance	Visual + auditory onboard info (49" screens + announcements)	Inner screen + app. Voice not specified
Securement (Trust & Safety)	Q'Straint docking + manual straps	Harness straps	Not specified
Key Strength	Wheelchair-Centric & Design Redundancy	Multi-Sensory Information & Flexible Interior Configuration	Inclusive Entry Design & Social Interior Space
Key Disadvantage	A dual security system creates an inequity	Human Operator Requirement	reliability and safety challenges wheelchairs securement

3.4 Case of service design tailored to older people

While previous sections focused on the physical and interior attributes of FAVs, this section shifts the focus to the service and interaction ecosystem that supports the mobility experience. For older people, the digital interface and the service journey are as critical as the vehicle itself in determining the usability of autonomous mobility.

Uber's Senior Account (Simple Mode) streamlines the app for older people. It simplifies the booking process with large text and buttons and a minimal screen that displays only essential information (Uber Technologies Inc., 2025).

The service offers a simplified experience with larger text, fewer buttons, and easy-to-follow screens, along with the ability to store frequent destinations, such as home or the doctor’s office, for quick access. It offers flexible payment options using a personal card, a family member’s card, or a Medicare Flex card for eligible medical rides. Users can receive trip updates, allowing loved ones to follow rides in real time and receive alerts if there is a delay. Additionally, support is available when needed, as family organizers can help book rides for the senior account holder and contact the driver if necessary (Manohar, 2025).

Another example is the Jitterbug smartphone. The Jitterbug smartphone's design emphasizes physical and interface features to enhance accessibility for older users.

- **Simplified Interface and Large Font:** The home screen features a single list-based menu with text labels rather than complex icons, making key functions like messaging, calling, and the camera straightforward. It uses a 6.75-inch high-contrast display with large fonts to aid visually impaired users (Lively Direct, n.d.; The Senior List, n.d.).
- **Audio and Hearing Aids:** It offers loud, clear audio through an amplified speakerphone and dual speakers. The device is Hearing Aid-Compatible (HAC) and includes Call Captioning, which converts speech to text for improved call accessibility (Hear World Communications, n.d.).
- **Voice Commands:** It features voice command support via Google Assistant and voice typing, assisting users who are uncomfortable with keyboard input (Lively Direct, n.d.).

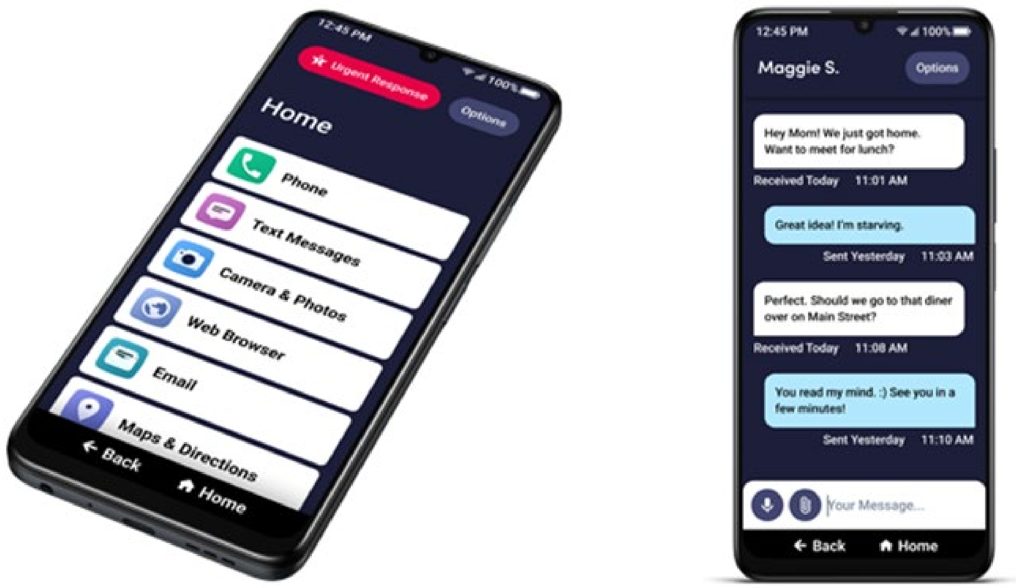


Figure 64. Jitterbug smartphone (Lively, n.d.).

Jitterbug combines easy hardware with proprietary services centered on older people's safety and health management.

- **Urgent Response System:** A prominent emergency button connects users immediately to a 24/7 certified emergency agent, tracks their location, and requests aid (Lively, n.d.; The Senior List, n.d.;).
- **Nurse On-Call:** Depending on the plan, users can call a registered nurse or doctor 24/7 for medical advice or to obtain minor prescriptions (Lively, n.d.).
- **Lively Rides and Caregiver Connection:** The Lively Link app enables caregivers and family to track the user's location and receive emergency alerts. Lively Rides also allows users to call and book ride-sharing services like Lyft by dialing "0," making the process simpler (Lively, n.d.; The Senior List, n.d.).

The Jitterbug smartphone shows how 'simplifying technology' and 'integrating life safety and health support services' can work together successfully. This design approach provides a smooth and innovative experience across different channels for the older people community. Despite these functional advantages, the Jitterbug smartphone has a significant design limitation when viewed through the lens of Inclusive Design (Chapter 2.4.6). By explicitly targeting and segregating the older people population as a distinct, marginalized group of technology users, the product inadvertently generates a social stigma. The specialized, overly simplified appearance and branding of such age-specific devices publicly signal the user's physical or cognitive decline, leading to reluctant adoption or emotional rejection by older adults who wish to avoid being labeled as frail or technologically incompetent.

3.5 Key Takeaways for Design Consideration

3.5.1 Physical Considerations

To compensate for age-related physical decline (e.g., reduced muscle strength, flexibility, and sensory deterioration), FAVs must provide the following physical accessibility and convenience features:

- **Seamless Entry and Egress**: As seen in the cases of Cruise WAV and Renault EZ-GO, incorporating a kneeling system (lowering the vehicle body) and an automatic ramp is crucial not only for wheelchair users but also for older individuals with limited mobility. Specifically, EZ-GO's front-opening hatch and ground lighting are vital safety features that clearly indicate the ramp's location, helping to prevent falls during boarding.
- **Physical Redundancy in Controls**: While Zoox and Renault EZ-GO tend to rely on smartphone apps or touchscreens, these interfaces can create barriers for older users with limited fine-motor skills. In contrast, Cruise WAV includes

physical buttons alongside touchscreens, allowing for intuitive, immediate use. This lessens the physical effort needed for manipulation and is a key part of fulfilling the principle of Equitable Use.

3.5.2 Cognitive and Sensory Considerations

Given the slower adoption of new technologies and reduced audiovisual perception among older people, information should be communicated clearly and through multiple senses.

- **Multi-Sensory Information Delivery:** May Mobility Murphy features a Synchronized Audio-Visual Feedback system that uses a large, curved 49-inch screen alongside simultaneous voice announcements. This is a key function that ensures older users with either visual or hearing impairments do not miss critical information. Cruise WAV also integrates external displays, internal screens, and voice guidance to reduce cognitive load and help users understand the situation.
- **Intuitive Interface and Affordance:** Olli 2.0 allows older users to interact as if conversing through natural language processing, eliminating the need to learn mechanical interfaces. This is an effective method for lowering cognitive barriers. Conversely, Zoox's smartphone app-based hailing method was identified as potentially causing cognitive overload for older users with low digital literacy.

3.5.3 Psychological and Emotional Considerations

Emotional design is necessary to resolve anxiety (Technology Anxiety) regarding autonomous driving technology and to build trust.

- **Anthropomorphism for Trust:** Olli 2.0's communication through eye-shaped screens and an external PA system lowers psychological barriers by framing the vehicle as a 'friendly entity' rather than a mere machine. This provides emotional stability to older users who may fear or be uncomfortable with FAV technology.

- **Social Connectivity:** The face-to-face or lounge-style seating arrangements in Zoox and Renault EZ-GO encourage social interaction during travel. This can play a positive role in relieving the social isolation often experienced by older people due to mobility restrictions.

Furthermore, when integrated with Mobility-as-a-Service (MaaS) systems. These interior layouts become even more impactful. MaaS platforms enable shared, on-demand travel among residents who might otherwise commute alone, creating opportunities for spontaneous social encounters within the vehicle. In real-world MaaS operations, older people not only benefit from accessible, reliable transportation but also from increased social engagement, as the service connects them with neighbors, community activities, and essential services.

3.6 Analytical Evaluation of FAVs Through the Lens of Anti-Stigmatization Design

This part critically examines current FAV case studies, including the Cruise Wheelchair Accessible Vehicle (WAV), May Mobility's Accessible Shuttle, Renault EZ-GO, Zoox, and Olli 2.0, using the anti-stigmatization design framework by Li, Lee, and Xu (2020), as discussed in Chapter 2.4.6. By assessing whether these vehicles address aspects like Aesthetic Appeal, Social Signifiers, Affordance, and Privacy, the study highlights the gap between functional accessibility and psychological dignity.

3.6.1 Cruise WAV Stigmatization and Anti-Stigmatization Factors

The Cruise WAV demonstrates that Purpose-Built Vehicles (PBVs) are superior to retrofits in aesthetics but struggle with the practicalities of Affordance and Privacy.

The primary stigma risk has shifted from ‘looking like a patient’ (aesthetic) to ‘acting like a patient’ (process/signifier) during the boarding phase. For example, the Cruise WAV succeeds in the ‘Aesthetic Appeal’ factor by using the same chassis and design language as the standard Cruise Origin. It avoids the ‘disability modification’ look of typical paratransit vans (e.g., raised roofs, bulbous lifts). However, the dual securement system creates a split in affordance. For users with compatible docking wheelchairs, the affordance is high (drive in, click, done). For manual wheelchair users (often older individuals with lower grip strength), the strap system has poor affordance, as it requires external assistance, violating the principle of independence.

3.6.2 Renault EZ-GO Stigmatization and Anti-Stigmatization Factors

EZ-GO ranks highest for ‘Aesthetic Appeal,’ resembling modern architecture more than a vehicle. Unlike traditional car entry, which involves a ‘crouch-and-twist’ motion exposing joint stiffness and frailty, EZ-GO enables users to walk in with dignity while standing upright. This design eliminates physical performance cues that typically reinforce ageist stereotypes. However, despite its aesthetic appeal, the transparency signifies a significant ‘Neglect of Privacy.’ Older adults frequently prefer to hide their vulnerability. Being in view in a glass enclosure while attending to a health issue or resting can create a ‘fishbowl effect,’ which might discourage use for fear of social judgment.

3.6.3 Zoox Stigmatization and Anti-Stigmatization Factors

Zoox looks like a premium consumer electronics product on wheels. It maximizes Aesthetic Appeal. Using a Zoox confers the status of being an early adopter of new technology. It is the antithesis of the medical/stigmatized aesthetic. It promotes a positive identity shift from old to modern. However, Zoox relies heavily on a smartphone app for hailing and entry. This presents Poor Affordance for the digitally excluded older people. If an older adult struggles to open the door with their phone while younger passengers wait, it can trigger Technological Anxiety and reinforce the stereotype of cognitive decline. Its app-centric interaction model creates a new form of Digital Stigma, in which competence is judged by one's ability to navigate a smartphone interface.

3.6.4 Olli 2.0 Stigmatization and Anti-Stigmatization Factors

Olli features a ‘cute and friendly’ face with digital eyes and a rounded, toy-like form factor. While this avoids the overly technical, strict look, it falls into the trap of Infantilization (benevolent ageism). In gerontechnology, designing products to look cute can be interpreted as treating older people like children. This undermines the user's authority and dignity, replacing the stigma of frailty with the stigma of childishness. However, Olli uses natural language processing (Voice interaction with AI). This offers an excellent Affordance. Speaking is a natural human capability that does not degrade as quickly as fine motor skills needed for touchscreens. It empowers the user to command the vehicle, restoring a sense of agency and competence.

3.6.6 Synthesis

The analysis reveals that while the industry is moving away from the medical aesthetic (improving Aesthetic Appeal), it is struggling to resolve the tension between Safety and Privacy/Signifiers. The visibility required for safety (glass walls, loud ramps, AVOs) directly contradicts the user's need for discretion and dignity.

3.7 Conclusion

This chapter’s comparison shows that although current FAVs have made notable technological advances, their capacity to address the varied needs of older individuals remains inconsistent. Each case study, covering aspects such as accessibility, interior flexibility, interaction methods, and sensing technology, demonstrates strengths. However, no single solution comprehensively meets the physical, cognitive, and emotional needs of older adults.

Some vehicles enhance accessibility with features like wide doors, ramps, or modular interiors, while others improve user interaction through multimodal sensing, simplified interfaces, or voice communication. However, misalignments still exist, especially in intuitive guidance, social comfort, and universal accessibility. These gaps underscore the need for a comprehensive design approach that provides spatial usability, ease of interaction, a feeling of trust, safety reassurance, social belonging, and effective service support.

Therefore, the next chapter will draw on the key takeaways from both chapters 2 and 3 and develop design guidelines to provide evidence-based guidance that ensures future autonomous vehicle solutions better meet the needs, limitations, and lived experiences of aging users.

Chapter 4 Design Guideline and Design Improvement

4.1 Overview

This chapter offers guidelines to enhance mobility and independence among older adults by incorporating principles from Universal Design, Inclusive Design, and Cognitive and Sensory Interaction. Designing FAVs for older people involves more than just enhancing physical access. It requires providing a complete User Experience (UX) that reduces technology anxiety and builds trust in automated systems.

Previous research on autonomous vehicles has mainly concentrated on perfecting engineering technicalities. However, older users often feel significant anxiety or fear due to the system's complexity and concerns about losing control in unexpected situations. Consequently, these guidelines are organized into three main areas: Physical Space, Human-Machine Interface (HMI), and Psychological Safety and trust building, considering age-related changes in body measurements and cognitive abilities.

By integrating these dimensions, this study proposes a holistic design framework that transforms the FAV from a mere technological artifact into an empathetic mobility partner for older people.

4.2 Tangible Features

The physical architecture of an FAV dictates the foundational level of accessibility for older users with mobility impairments, ranging from reduced joint flexibility to reliance on walking aids or wheelchairs. Reimagining vehicle ingress, egress, and interior circulation is necessary. For instance, Cruise’s WAV has a retractable ramp, kneeling suspension to lower the floor, double-wide doors, and floor clamps to secure wheelchairs. May Mobility's shuttles use an ADA-compliant ramp and a flexible harness that accommodates nearly any wheelchair, with an AVO assisting riders with boarding and securing their chairs. Vehicles should also include physical supports, such as stability bars, and sufficient knee and hip clearance to facilitate easier entry and exit.

4.2.1 Physical Space and Accessibility Guidelines

FAV boarding areas should accommodate wheelchairs and scooters. For example, Cruise's new autonomous WAV features a low-floor chassis, double-wide side doors, and an automatic ramp to align with curb height, enabling smooth wheelchair entry. Vehicles should kneel or lower at stops and deploy a ramp with handrails and warning lights for safety. Wide, sliding, or double doors, along with sufficient aisle space, are essential. Grab bars and seatbelts must be reachable and easily operable (e.g., simple latches), and lighting should be ample on steps and ramps to help older eyes. Seats can swivel or raise to reduce bending, and floors should be slip-resistant.

4.2.1.1 Ramp & Kneeling System

Due to spatial constraints, vehicles allow for steeper slopes than buildings. The design and mechanical execution of automated ramps must strictly adhere to the ADA and 49 CFR Part 38 requirements to safely accommodate the weight and footprint of heavy motorized wheelchairs and to prevent user fatigue during manual propulsion. For wheelchair users, ramp runs shall have a running slope not steeper than 1:12. However, given the vehicle's physical space constraints and the need for rapid ingress and egress, a slope ratio of 1:8 is recommended to optimize efficiency, based on the vehicle height achieved when the kneeling system is fully deployed.

Table 3. 49 CFR 38.23 - Mobility aid accessibility (Transportation for Individuals With Disabilities, 2026).

Slope	Maximum Rise Including 6-inch curb
Ramps shall have the least slope practicable and shall not exceed 1:4 when deployed to ground level.	Less than 3 inches
Minimum slope of 1:6	3 - 6 inches
Minimum slope of 1:8	6 - 9 inches
Steeper than 1:12 but not steeper than 1:10	More than 9 inches

Also, ramps measuring 30 inches or more must support a 600-pound load, applied at the center and spread over a 26-inch-by-26-inch area, with a safety factor of at least 3 relative to the material's ultimate strength. Ramps shorter than 30 inches must support a 300-pound load. The ramp surface must be continuous and slip-resistant, with no protrusions exceeding ¼ inch in height. It should have a clear width of 32 inches and be suitable for both four-wheel and three-wheel mobility aids. The transition from the roadway or sidewalk to the vehicle floor, and from the vehicle floor to the ramp, can be vertical up to ¼ inch without edge treatment. For level changes between ¼ inch and ½ inch, beveling with a slope not exceeding 1:2 is required. Additionally, each side of the ramp must have barriers at least 2 inches high to prevent mobility aid wheels from slipping off (see Figs 65 and 66).

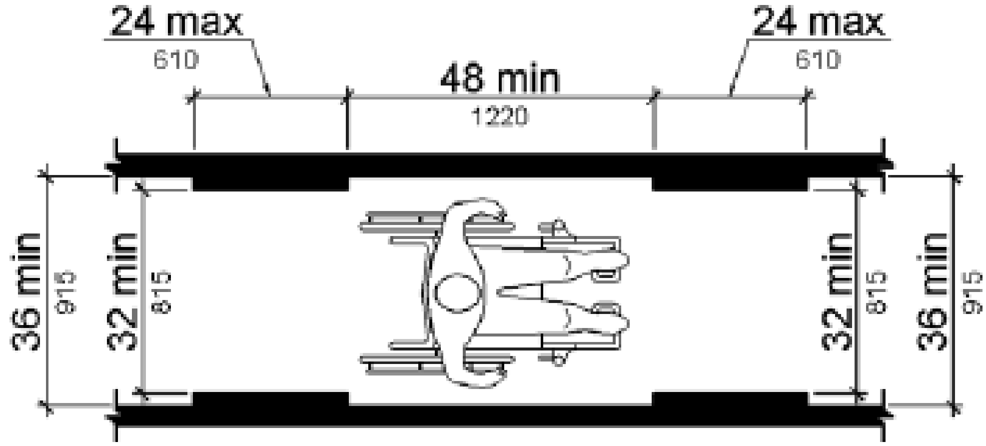


Figure 65. ADA 403.5.1 Clear Width (U.S. Access Board, n.d.).

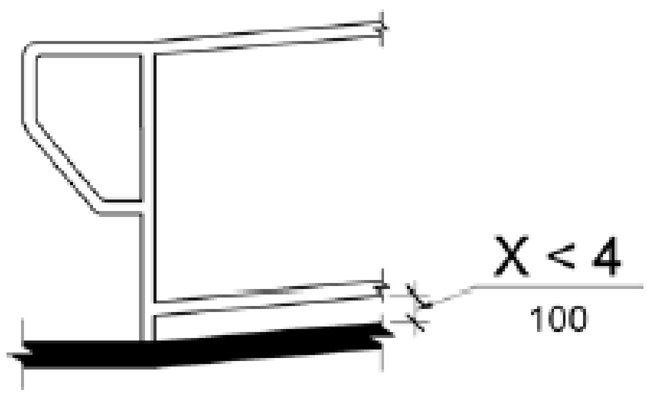


Figure 66. ADA Ramp Barrier (U.S. Access Board, n.d.).

Ramps must use the appropriate option depending on the conditions, either fold-out or in-floor. In-floor ramps, which slide under the floor, offer a clean, unobstructed entryway, making them ideal for caregivers, for higher ground clearance, and for avoiding interior clutter. It will fit with vehicles such as Zoox and WAV. Fold-out ramps, which stow against the door, are generally less expensive, often feature higher side rails for security, and are better suited, but can be noisier and block the doorway. They will fit with a vehicle such as an EZ-GO.

Figure 67. In-floor and Fold-out ramp (Aero Mobility, 2023).

4.2.1.2 Door

Doorway architecture dictates the fluidity of the transition from the ramp into the cabin. Passenger doorways must provide a minimum clear opening of 32 inches, with a recommended 34-36 inches for large wheelchairs when fully open. This dimension ensures that wider bariatric wheelchairs or older people using walkers with an attendant can enter without scraping the doorframes, thereby mitigating the risk of injury and the associated anxiety. To optimize this accessibility, double-wide automatic sliding doors or subway-style bi-parting doors (48 inches) are highly recommended. Unlike traditional swinging doors, subway-style doors do not encroach on crowded streets or narrow sidewalks, ensuring the vehicle's physical mechanism does not become an external hazard. Immediately inside the doorway, high-contrast, texturized grab bars must be installed to provide continuous structural support for ambulatory older adults transitioning from a standing to a seated posture.

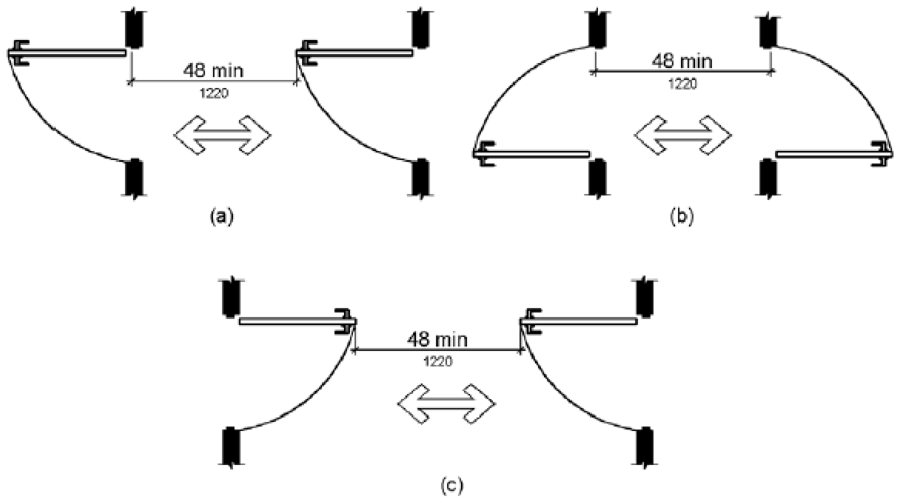


Figure 68. ADA 404.2.6 Doors in Series and Gates in Series (U.S. Access Board, n.d.).

4.2.1.3 Door Handles

Door handles are essential features that promote accessibility and safety for individuals with physical disabilities. They help ensure that everyone can access and operate vehicles with ease. However, it is important to emphasize that installing or placing door handles should not interfere with or obstruct the vehicle's normal access. Proper planning and design are necessary to balance accessibility features with unobstructed vehicle entry and exit.

Hardware components such as handles, pulls, latches, locks, and other operable parts should be installed between 34 inches (865 mm) and 48 inches (1220 mm) above the finished floor or ground. When sliding doors are fully open, the hardware must be accessible and functional from both sides. Operable parts should be operable with one hand without requiring tight grasping, pinching, or wrist twisting. The force needed to activate these components should not exceed 5 pounds (22.2 N).

4.2.2 Interior Design

Once the threshold is crossed, the interior spatial configuration must alleviate the physical stress of maneuvering in confined spaces. An open, completely flat, low-floor layout is non-negotiable.

Waymo's Q3 2025 occupancy data show that over 90% of FAV trips have two or fewer passengers. This indicates that, most of the time, the vehicle used greatly exceeds the trip's requirements. According to this research, the optimal setup is 1 wheelchair and 2 passengers.

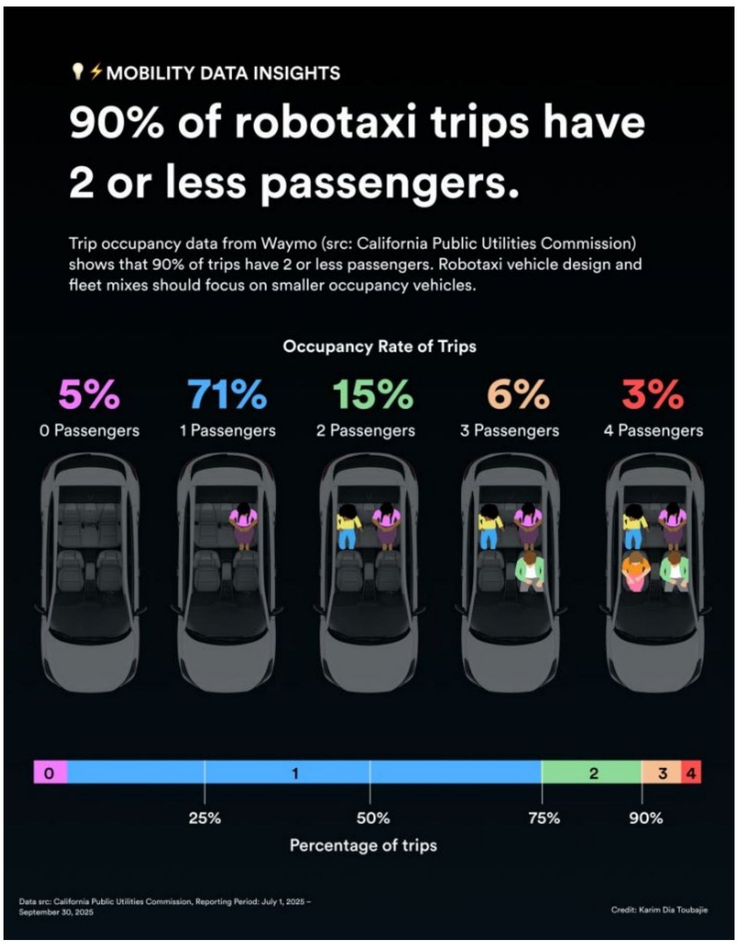


Figure 69. Occupancy Rate of Trips (Toubajie, 2025).

4.2.2.1 Route Space

The interior should maximize clear space and flexibility. A flat floor with minimal steps (made possible by the absence of a driver's cockpit) allows passengers to circulate easily. Seat layouts can be “social” (e.g., face-to-face benches) to encourage interaction, but must preserve clear aisles. Regarding Protrusion Limits, for older people using walking aid kits such as canes or walkers, control panels and other components are positioned at least 27 inches above the floor and do not protrude more than 4 inches.

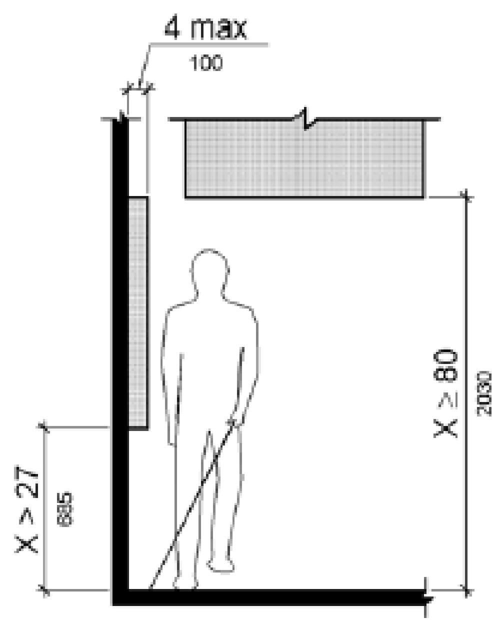


Figure 70. ADA 307.2 Protrusion Limits (U.S. Access Board, n.d.).

4.2.2.2 Seat

The seat design of FAVs is evolving into a universal design that embraces all users, moving away from the constraints of driving. Accessibility and inclusivity for users with mobility impairments or wheelchair users are emphasized as key design elements.

In particular, FAV interiors promote a 'moving living room' concept, departing from the traditional fixed forward-facing seat arrangement. For ambulatory seniors or those who choose to transfer from a mobility aid to a vehicle seat, the seating ergonomics must account for the musculoskeletal degradation inherent to aging. Aging manifests as reduced joint flexibility, loss of muscular strength, and changes in spinal curvature, fundamentally altering how a seat belt fits and how comfort is perceived. Ergonomic studies indicate that the optimal car seat for older adults should feature a variable seat bottom depth and an adjustable seat height.

This is a product actually used in currently operating low-speed autonomous shuttles (e.g., EasyMile EZ10, Olli). It is highly durable and features a cantilever (wall-mounted) design without legs, maximizing floor space and improving wheelchair accessibility. The seat's technology and specifications comply with the TSI-PRM standards and are designed with accessibility for people with mobility challenges in mind. The seat width is at least 450mm, and the seat for two people is 1050mm wide. The total height is 1270mm, with an armrest height of 690mm and a seat height of 460mm. Additionally, the seat depth, including the backrest, is 640mm.

Figure 71. Franz Kiel GmbH Seats (Franz Kiel GmbH, n.d.).

4.2.2.3 Wheelchair Space

A single wheelchair space must be at least 36 inches (915 mm) wide. When two wheelchair spaces are side by side, each must be at least 33 inches (840 mm) wide. For a front or rear entry, the space must have a minimum clear length of 48 inches (1220 mm). However, if the wheelchair must enter from the side, a minimum clear length of 60 inches (1525 mm) is required to allow for the necessary turning radius and positioning. These spatial requirements are critical to accommodating various types of mobility aids and ensuring an inclusive interior layout. The space required for a wheelchair to make a 180-degree turn is a clear space of 60 in (1525 mm) in diameter or a T-shaped space.

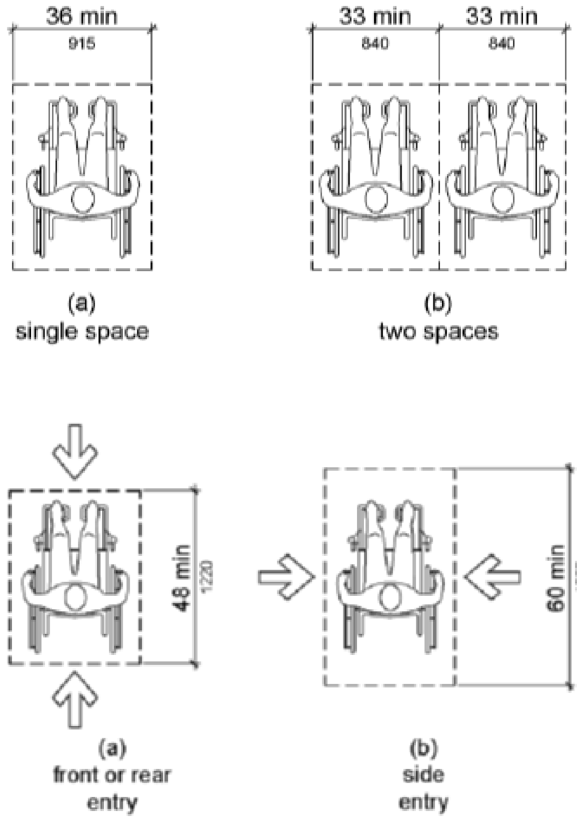


Figure 72. ADA 1002.4.4.3 Permitted Protrusions in Wheelchair Spaces (U.S. Access Board, n.d.)

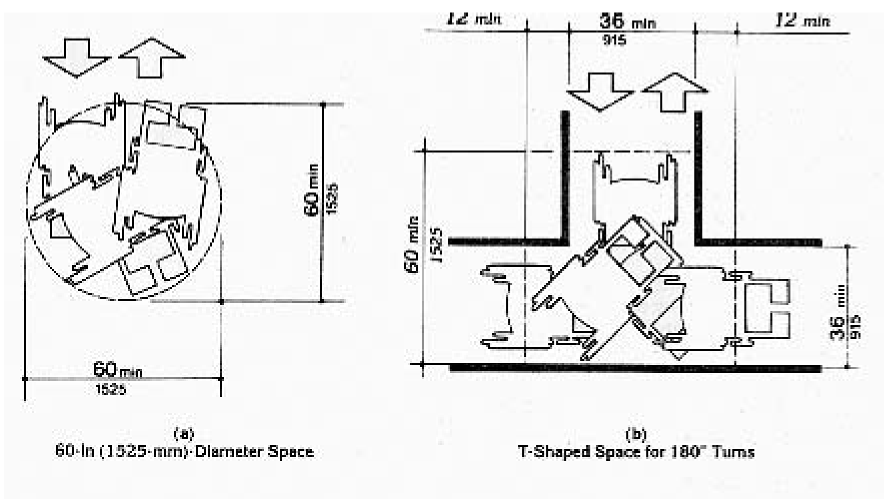


Figure 73. ADA 4.2.3 Wheelchair Turning Space (ADA Compliance Directory, 2026)

4.2.2.4 Wheelchair Locking System

A major critique of current accessible FAVs is the inequity in securement. Relying solely on manual wheelchair straps requires companion or operator assistance, which completely undermines the core value of autonomous, independent mobility for the disabled user. Conversely, offering only an automated dock alienates users with older or manual wheelchairs that lack the necessary locking pin.

The dual system provides ultimate flexibility and equitable use. Users with compatible power chairs can drive over the automated dock, securing themselves instantly and independently. For users with manual wheelchairs, the secondary strap system acts as a universal backup. Both systems comply with ISO 10542-1 standards for forward- and rear-facing tie-downs, ensuring the passenger's physical safety is never compromised during transit.

Figure 74. Wheelchair Auto Docking System (Q'STRAINT, n.d.).

Figure 75. Quantum Fully Automatic Wheelchair Securement System (Q'STRAINT, n.d.).

Figure 76. Manual Wheelchair Locking System (Q'STRAINT, n.d.).

4.2.2.5 Control Panel and Display

Control panels and displays must be conveniently located for wheelchair users. They must be at least 15 inches from the floor and no higher than 48 inches. Furthermore, if there is an obstruction that protrudes more than 10 inches, its maximum height must not exceed 46 inches. Furthermore, frequently used interactions must be positioned within a reach range of 17 to 47 inches from the floor to ensure optimal accessibility.

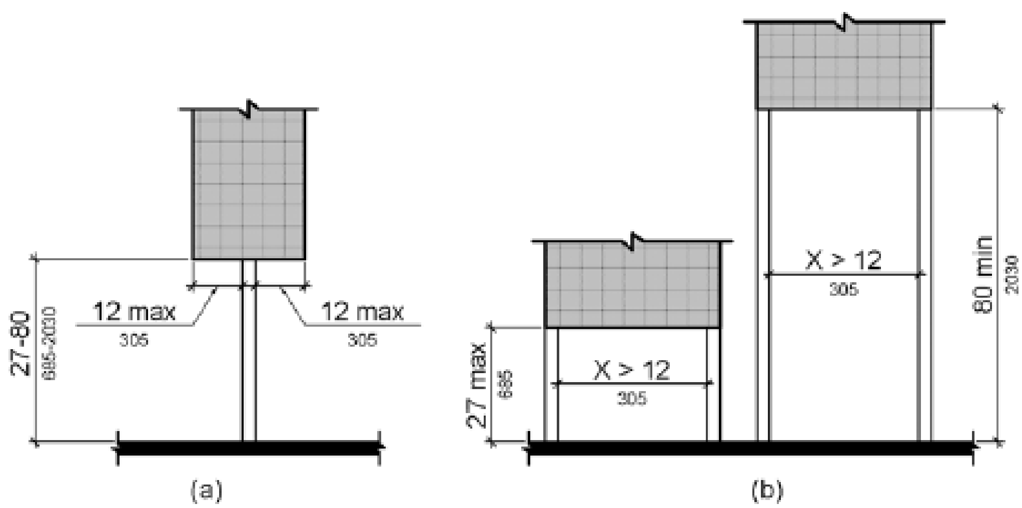


Figure 77. ADA 307.3 Post-Mounted Objects (U.S. Access Board, n.d.).

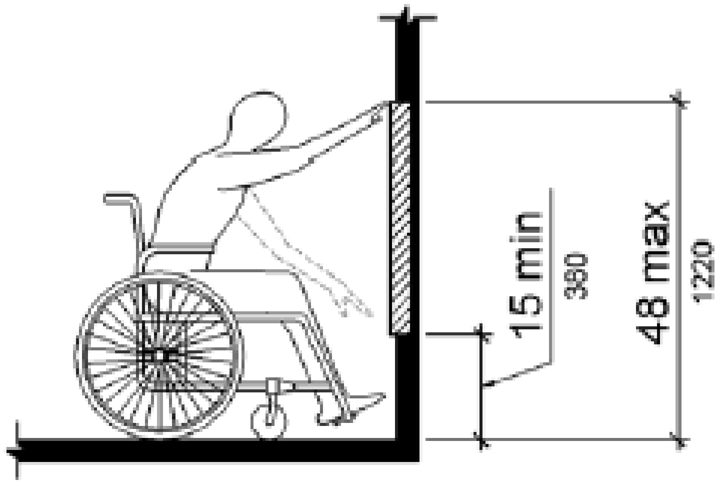


Figure 78. ADA 308.2.1 Unobstructed High Reach (U.S. Access Board, n.d.).

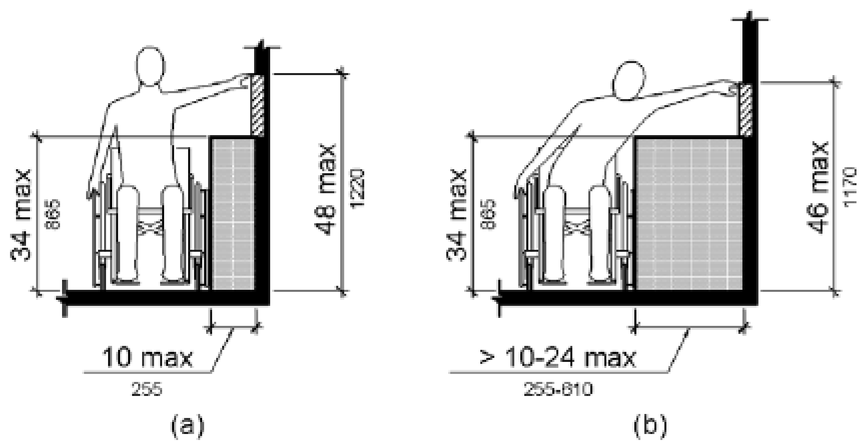


Figure 79. ADA 308.2.1 308.3.2 Obstructed High Reach (U.S. Access Board, n.d.).

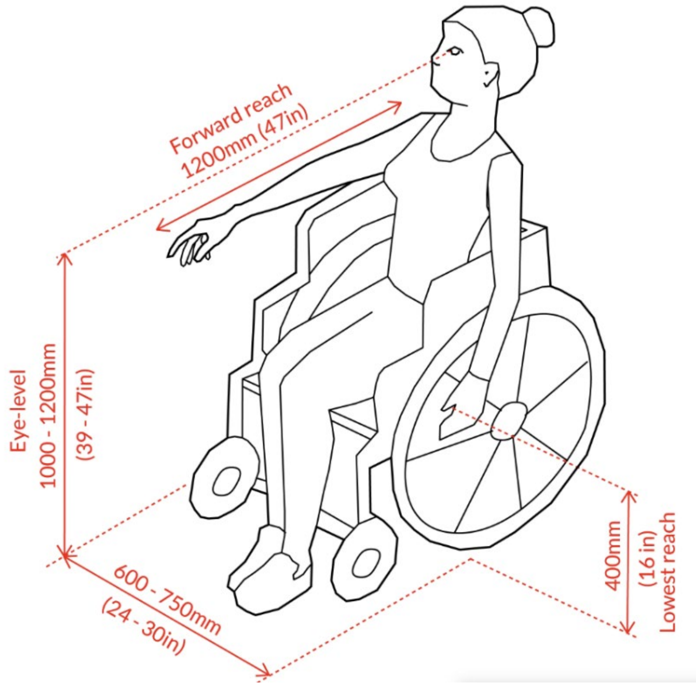


Figure 80 Wheelchair user reach (Post Digital Architecture, 2026)

4.2.2.5 Storage Space and Cargo Securement

When designing for the temporary storage of shopping bags, personal items, or secondary mobility aids such as walkers, the physical layout must prioritize accessibility without compromising internal circulation. The widespread phenomenon known as the 'bag of bags'—where unstructured, soft-sided shopping bags spread across the floor—creates dangerous clutter that can easily entangle wheelchair casters or trip ambulatory seniors. If storage solutions encroach on the floor space, they actively undermine the vehicle's fundamental accessibility. According to Post Digital Architecture (2026), traditional storage options often include high shelves and deep cabinets that can be difficult to reach from a seated position. More practical alternatives include:

- Low Shelves and Cabinets: Installed on walls up to 48 inches high from the floor.

- Pull-Out Features: Sliding drawers, baskets, and adjustable shelves enable easier access to stored items without deep reaching.
- Open Storage: Eliminates doors that might block wheelchair access.

To prevent the loss of personal belongings, all storage compartments are equipped with sensors that detect remaining items before the passenger exits the vehicle. When an object is detected, the system provides an immediate alert. To accommodate the sensory needs of older users, these notifications should be delivered through a multimodal interface that combines auditory cues with visual highlights on the cabin display. This proactive feedback loop not only ensures that essential items such as mobility aids or bags are not left behind but also reinforces a sense of psychological security by reducing the cognitive load of managing personal inventory during the journey.

4.2.3 Emergency Considerations

Safety engineering in FAVs must be proactive and highly visible to counteract the profound psychological anxiety older adults experience when surrendering control of their mobility to an automated system. An easy-to-find emergency button or intercom should connect the passenger to a remote operator or emergency services. Informational displays should clearly mark exits and protocols (e.g., “Emergency stop” or “Call for help”). Install restraint systems (seatbelts and, if needed, airbags) that are easy to use. For example, single-pull seatbelts and audible click confirmations help ensure proper use.

Furthermore, seatbelts should incorporate automatic, motorized retractors that remove slack in response to crash-avoidance system activations, firmly securing the torso before an impact. Emergency lighting (floor path lights) aids in evacuation. It is advisable to have a manual door release in case of a power failure. Consider installing an interior camera or sensor in the vehicle to identify falls or medical emergencies. Also, ensure there is at least one method for the passenger to communicate with an operator, such as voice communication or an assistive app. These measures help reassure passengers that help is accessible if necessary.

4.2.3.1 Emergency Button

Emergency intervention controls must be designed with redundancy and accessibility in mind. Emergency contact buttons and manual door release levers must be strategically placed within the ADA-mandated forward and side reach limits, which typically require that operable parts be located no higher than 48 inches and no lower than 15 inches above the floor (refer to Obstructed High Reach). Tactile, physical buttons labeled with high-contrast text must complement digital touchscreens. This ensures that in the event of a catastrophic power failure or a software glitch, a senior passenger, who may be experiencing panic, can easily bypass the digital interface, manually override the automated doors, and safely exit the vehicle.

4.2.3.2 Air Bag

Standard forward-facing airbags, designed around the layout of traditional steering wheels, are entirely insufficient given the non-traditional seating arrangements often found in FAVs such as the carriage-style, face-to-face seating seen on the Zoox platform. Therefore, completely reimagined safety restraints must be implemented. Multidirectional, U-shaped airbags that deploy in Zoox to protect the head, neck, and chest from frontal, rear, side, and rotational collisions are critical to providing 360-degree crash protection regardless of the vehicle's direction of travel.

4.2.4 Physical Space and Accessibility Checklist

Physical Space and Accessibility Checklist For Inclusive FAVs

Ingress/Egress Mechanisms and Mobility Aid Accessibility Design

Done	Component	Considerations	Requirements
☐	Ramp	In-floor and Fold-out ramp, LED light	Minimum 1:4 and Max slope 1:12 based on height from ground; 600 lb capacity; 2-inch edge barriers; LED light for visible
☐	Kneeling System	Active suspension lowering	Matches curb height to minimize transition gap
☐	Door Width	Double-wide sliding doors	Minimum 32 inches (1220 mm) clear opening. Recommended between 34-36 inches for the large wheelchair
☐	Door Hardware	Door Handle	Low physical effort operation, 34-48 inches high; < 5 lbs force; operable with closed fist

Interior Design

Done	Component	Considerations	Requirements
☐	Interior Routing	Completely flat floor	Other components are positioned at least 27 inches above the floor and do not protrude more than 4 inches for walking aid kits
☐	Wheelchair Space	Permitted Protrusions in Wheelchair Spaces	A single wheelchair space must be at least 36 by 48 inches. 60 inches turning diameter for wheelchairs
☐	Wheelchair Lock Securements	Docking, Fully Automatic, Manual	Automatic or Docking Securement + Manual Securement backup. Seat belt
☐	Control Panel and Display	Physical button and touch screen	At least 15 inches from the floor and no higher than 48 inches. if there is an obstruction that protrudes more than 10 inches, the maximum height must not exceed 46 inches
☐	Seat	Foldable	The seat width is set at least 450mm, and the seat for two people has at least a width of 1050mm
☐	Storage and Cargo	Equipments holders, Low Shelves, Cabinets	Placed between 15 and 48 inches from the floor. Eliminates doors that might block a wheelchair.

Emergency Considerations

Done	Component	Considerations	Requirements
☐	Emergency Buttons	Multiple redundant method: Physical, App, Touch panel	Placed between 15 and 48 inches from the floor. Well-marked and colored for quick noticing
☐	Airbags	U-shaped deployment airbags	Multidirectional airbag protection for face-to-face seating

Figure 81. Physical Space and Accessibility Checklist

4.3 Intangible Features

4.3.1 Cognitive and Sensory Interaction Guidelines

As physical barriers are systematically dismantled, the interaction between the user and the vehicle's digital ecosystem must be carefully designed. Cognitive changes associated with aging, such as slower information processing, reduced short-term memory, and diminished executive function, together with sensory degradation in vision and hearing, make traditional digital interfaces overwhelming for older adults. The redesign shifts the operational paradigm from smartphone dependency to an integrated, highly legible, multimodal in-cabin experience that actively calibrates user trust.

4.3.1.1 Intuitive and Step-by-Step User Experience

The cognitive decline inherently associated with the aging process necessitates an interaction architecture that drastically mitigates mental workload. Older adults frequently experience reductions in working memory capacity and processing speed, making dense, feature-heavy interfaces highly intimidating. When an older person attempts to engage with an FAV routing protocol, climate control systems, or emergency communication networks, presenting a multitude of options simultaneously on a single screen reliably induces cognitive overload, often resulting in complete task abandonment. Therefore, a structured ‘Step-by-Step Process’ in UX/UI design is an absolute prerequisite for alleviating technology anxiety in autonomous vehicles. To counteract this friction, the digital HMI must deconstruct complex operational maneuvers into sequential, singular inputs based on the ten perspectives from Chapter 2.4.10.

Figure 82. Step-by-Step User Flowchart from Boarding to Departure

The redesign incorporates physical buttons and a layered onboarding process on the interior touchscreens to streamline tasks—such as route confirmation, climate control adjustments, and support contact—into a foundational interaction sequence (e.g., Select Destination → Confirm Route Options → Adjust Interior Seating → Initiate Journey). By dividing these tasks into clear procedures with explicit 'Go Back' and

'Confirm' options, the interface effectively reduces cognitive fatigue and boosts user self-confidence. Furthermore, the integration of visible error-recovery buttons, consistent layout, and familiar navigation patterns minimizes the learning curve. Ultimately, these elements work together to transform the vehicle from intimidating high-tech equipment into a simple, user-friendly service.

Figure 83. Zoox Seat belt alert (Zoox, 2025).

Zoox Seat Belt Alert serves as a primary example of providing a clear process by decomposing complex interactions into manageable stages. Zoox utilizes a ‘Step-by-Step Verification Process’ where the system ensures that specific actions are completed before allowing the user to proceed to the next phase of the journey. By implementing these sequential constraints, the interface prevents the progression of the task until essential safety requirements are met.

For older adults, who may experience higher cognitive loads or technology-induced anxiety, this design provides a deterministic and transparent path. It eliminates ambiguity by clearly defining ‘what to do now’ before ‘what happens next.’

Consequently, this structured flow helps users build trust with the autonomous system, ensuring a safe and predictable transition from boarding to departure.

4.3.1.2 Visual and Graphic Clarity

The Digital Accessibility Office (2026) recommends a contrast ratio of 4.5:1 between colors for accessible text, ensuring readability for users with moderate low vision or color blindness. For bold text at least 19px or text at 24px and larger, the minimum contrast ratio is 3:1. Also, interactive elements such as tabs and buttons should aim for a 3:1 contrast ratio. Effective color contrast enhances content visibility across various devices and lighting conditions.

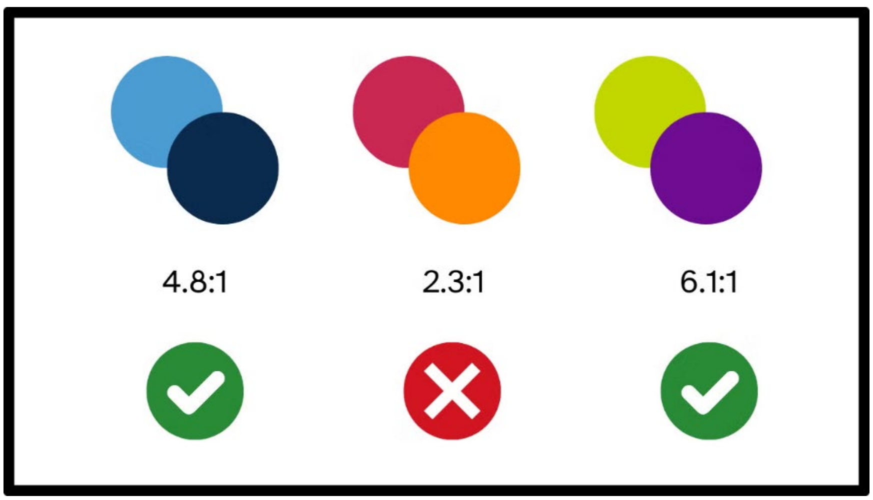


Figure 84. Color Contrast (Digital Accessibility Office, 2026).

The stringent adherence to visual character heights and contrast ratios ensures that route progress, arrival times, and emergency prompts are immediately and effortlessly legible. The avoidance of blue for critical interactive elements, favoring bold, highly contrasted buttons, helps users keep track of the interface hierarchy. Pairing icons with text eliminates ambiguity, ensuring that users do not have to rely on working memory to operate the vehicle's secondary functions.

Table 4. Visual and Graphic Clarity

Height to Finish Floor or Ground from Baseline of Character	Horizontal Viewing Distance	Minimum Character Height
40 inches (1015 mm) to less than or equal to 70 inches (1780 mm)	less than 72 inches (1830 mm)	5/8 inch (16 mm)
40 inches (1015 mm) to less than or equal to 70 inches (1780 mm)	72 inches (1830 mm) and greater	5/8 inch (16 mm), plus 1/8 inch (3.2 mm) per foot (305 mm) of viewing distance above 72 inches (1830 mm)
Greater than 70 inches (1780 mm) to less than or equal to 120 inches (3050 mm)	less than 180 inches (4570 mm)	2 inches (51 mm)
Greater than 70 inches (1780 mm) to less than or equal to 120 inches (3050 mm)	180 inches (4570 mm) and greater	2 inches (51 mm), plus 1/8 inch (3.2 mm) per foot (305 mm) of viewing distance above 180 inches (4570 mm)
greater than 120 inches (3050 mm)	less than 21 feet (6400 mm)	3 inches (75 mm)
greater than 120 inches (3050 mm)	21 feet (6400 mm) and greater	3 inches (75 mm), plus 1/8 inch (3.2 mm) per foot (305 mm) of viewing distance above 21 feet (6400 mm)

4.3.1.3 Human-Machine Interface

Delivering information in multiple ways ensures information redundancy. Even if visual cues on the screen are missed, voice prompts (e.g., "Obstacle detected, slow down") provide passengers with continuous information. Furthermore, providing users with multiple control options (e.g., "physical buttons, touchscreen, voice control") improves accessibility. These options restore users' autonomy and proficiency, dramatically reducing the cognitive burden associated with learning new technical workflows.

Drawing on the Flourish Best Practice guidelines for effective AV interfaces, the HMI was designed to be highly adaptable, allowing users to personalize settings such as font size, color contrast, and voice speed to suit their needs. The interface also strictly adheres to core trust-building principles: making interactions Simple, Consistent, Accessible, and Clear (see Chapter 2.4.8).

4.3.1.4 Adaptability

Personalizing settings are particularly effective at helping users acquire and use a product's affordances more quickly. Since older people exhibit significant individual differences in the progression of aging and physical capabilities, such as vision, hearing, and reaction speed, an interface that is adjustable to individual needs is essential rather than a one-size-fits-all approach.

In Visual Adjustments, settings can be adjusted. Users can increase font size or switch to a high-contrast theme. The speech rate and volume of voice guidance can be changed to match hearing ability. This adaptivity reflects ISO 9241's emphasis on user customization. A guided setup on first use helps users choose comfortable defaults. Long-term usage data (dwell time, error frequency) could automatically suggest adjustments.

4.3.1.5 Cognitive and Sensory Checklist

Cognitive and Sensory Interaction Checklist
For Inclusive FAVs

Cognitive and Sensory Element			
Done	Component	Considerations	Requirements
☐	Task Structure	Step-by-step sequential flow	Design Insights for Effective Autonomous Vehicle Interface Design
☐	Typography	Legible, sans-serif fonts	Min. 5/8 inch character height for < 72 in. viewing distance
☐	Color & Contrast	High contrast, no color dependency	Avoid blue for critical elements; provide grayscale alternatives
☐	Iconography	Familiar and text-paired	All icons must include descriptive labels to prevent ambiguity
☐	Human-Machine Interface (HMI)	Simple, Consistent, Accessible, and Clear.	10 Design insight for Effective Autonomous Vehicle Interface Design
☐	Multimodality	Information and control redundancy	Offer various redundancy options: physical button, touch screen, and voice control
☐	Adaptability	Personalization of settings	Adjustable font size, interface speed, and voice volume
☐	Real-time System Feedback and Transparency	Keep the User Informed, Unplanned Halts	Provide real-time voice and visual feedback to clearly and transparently explain the vehicle's action logic

Figure 85. Cognitive and Sensory Checklist

4.3.2 Psychological Safety and Trust-Building Guidelines

Beyond the mechanics of physical access and the clarity of cognitive interaction, the successful, long-term adoption of autonomous mobility hinges on emotional resonance and psychological safety. Vehicles and devices designed explicitly for the disabled or older people frequently carry a heavy social stigma, acting as visual symbols of frailty, incompetence, and dependency. The redesign strategies applied in this section aim to neutralize these stigmas, replacing them with a sense of dignity, while actively building calibrated trust through environmental psychology and service-level integration.

4.3.2.1 Anti-Stigmatization

Anti-stigmatization design ensures that a product or service does not serve as a visual or social 'marker' of a user's physical or cognitive vulnerabilities. Older adults often reject assistive technologies, such as traditional mobility aids or overly simplified senior phones, because these products carry social stigmas associated with frailty, incompetence, and dependency. To successfully integrate older users, Inclusive FAVs must be perceived as modern, sophisticated mobility solutions for everyone, rather than "special" vehicles for older people.

Following the stigma perception model 'Conceptual model of stigma perception in a design domain (Li et al., 2020), designers must mitigate four primary triggers of identity threat: Lack of Aesthetic Appeal, Accentuated Social Signifiers, Poor Affordance, and Neglect of Privacy. For instance, while expansive glass windows in vehicles like the Renault EZ-GO may look futuristic, they create a "fishbowl effect" that severely neglects the privacy of older adults who may feel vulnerable while managing mobility aids. Similarly, relying exclusively on smartphone applications for vehicle access (as seen in the Zoox platform) creates "Digital Stigma" due to poor affordance for the digitally excluded older people. Furthermore, designers must avoid the trap of "benevolent ageism" or infantilization—such as the toy-like aesthetics of Olli 2.0—which undermines the user's dignity. Instead, inclusive FAVs should employ "Invisible Design

Features," integrating assistive elements seamlessly into a premium, universal aesthetic so that accessibility does not compromise social identity (see chapter 2.4.10).

4.3.2.2 Affordance and Mental Models

The physical and digital environments were meticulously mapped to align with natural human expectations and existing mental models. Door handles are shaped to visually suggest the act of pulling, while physical emergency buttons are elevated, brightly colored, and contoured to invite pushing. Digital interfaces leverage familiar metaphors, such as traditional gauge layouts for speed or progress (see chapter 2.4.6 & 2.4.8).

By ensuring that the perceived properties of the vehicle's controls exactly match their actual functional operations, users inherently know what to do without requiring pictorial labels or complex instructions. This intuitive physical and cognitive mapping empowers the older adult, reinforcing their competence and subjective agency within a highly automated environment.

4.3.2.3 Mobility as a Service (MaaS)

The vehicle's software ecosystem is seamlessly integrated into a broader community Mobility-as-a-Service (MaaS) platform. The vehicle interface allows for synchronization with caregiver applications, enabling family members or medical providers to book rides, track the vehicle's location in real time, and receive instant emergency alerts. The service model is also integrated with local medical and social community transit networks (see chapter 2.5.1.2).

Connecting the FAV to a MaaS network transforms the vehicle from a simple product into a holistic life-support service. The ability for a trusted caregiver to monitor a trip provides profound psychological reassurance to both the passenger and their family, drastically reducing the fear of becoming stranded or experiencing a medical event alone. By facilitating shared, on-demand travel among community residents, this integrated approach lowers initial adoption resistance, drives sustained platform uptake, and actively combats the severe social isolation prevalent in aging populations.

4.3.2.4 Anthropomorphic

Older adults often experience significant technology anxiety due to fears of losing control to opaque, algorithm-driven processes. Chapter 3.2.1 The Olli 2.0 case study highlights that anthropomorphism, attributing human traits, intentions, and emotions to non-human entities, is an effective psychological strategy for bridging the emotional gap between complex automated systems and vulnerable users. This suggests that when non-human agents are endowed with human-like qualities, users are more likely to trust their competence and safety.

However, designers must exercise profound caution to avoid the detrimental phenomenon of 'benevolent ageism' or infantilization. While highly anthropomorphized, toy-like designs may appear approachable, they can inadvertently strip older adults of their dignity, replacing the stigma of physical frailty with that of childishness.

Furthermore, empirical analyses suggest that over-anthropomorphizing a system does not uniformly guarantee increased trust and, in some edge cases, can create unrealistic expectations regarding the vehicle's capabilities, leading to severe trust degradation if a system failure occurs. Therefore, the optimal anthropomorphic implementation for inclusive FAVs relies on functional, transparent communication rather than mere aesthetic mimicry. A conversational AI that utilizes natural language processing to articulate its reasoning (e.g., “I am adjusting our route due to heavy traffic ahead”) provides the necessary cognitive reassurance without condescension, ensuring that trust is continuously and accurately calibrated throughout the journey.

4.3.2.5 AVO Service

Although SAE Level 5 autonomous vehicles have largely removed the need for human drivers, May Mobility’s Autonomous Vehicle Operator (AVO) service may still be essential, especially for vulnerable populations, during the transition period. The AVO system provides human oversight, with interventions from an onboard safety attendant. This hybrid setup helps to connect advanced technology with human-centric, empathetic service (see Chapter 3.3.2).

For users with severe mobility impairments, automated deployment of an ingress ramp often falls short if the passenger struggles with the final physical alignment needed to engage the vehicle's automated wheelchair lock. An onboard AVO offers direct physical help, ensuring manual wheelchair tie-down straps are securely fastened and providing immediate cognitive reassurance. As autonomous fleets expand to serve larger metropolitan areas, the remote AVO model will become the main method for system management.

4.3.2.6 Psychological Safety and Trust-Building Checklist

Psychological Safety and Trust-Building Checklist

Service and Interaction Component		
Done	Component	Considerations
☐	Anti-Stigmatization	Neutralize visual/social markers of vulnerability (frailty, incompetence)
☐	Affordance Mapping	Intuitive physical/digital interaction aligned with existing mental models
☐	Community MaaS	Local service integration or collaboration
☐	Caregiver Connectivity	Remote monitoring and psychological reassurance
☐	Anthropomorphic Communication	Functional transparency to build calibrated trust without condescension; A conversational AI that utilizes natural language processing to articulate its reasoning Avoid the detrimental phenomenon of 'benevolent ageism' or infantilization
☐	AVO Service	Human oversight and physical assistance;

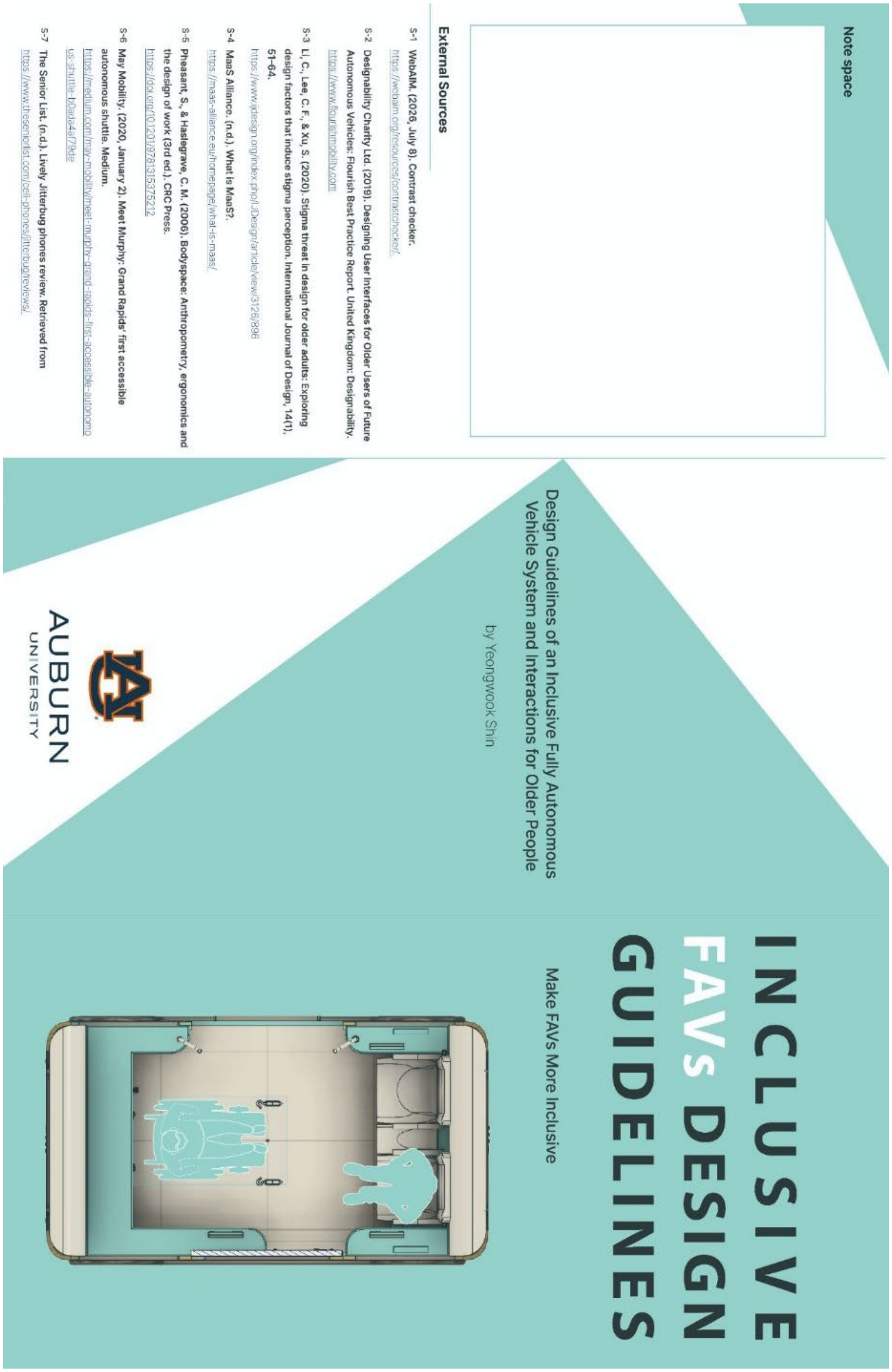
Figure 86. Psychological Safety and Trust-Building Checklist

4.4 Design Guidelines Pamphlet

This pamphlet provides practical guidance for the effective and efficient design of Inclusive FAVs for the elderly and the mobility-impaired, drawing on key insights from Chapters 2, 3, and 4 of this study.

It helps designers and engineers quickly understand the physical, cognitive, and psychological needs of elderly users, who are particularly vulnerable to mobility exclusion amid advances in electrification and autonomous driving, and provides essential design principles and checklists in an intuitive handbook format.

The back page of this pamphlet features a "Design Checklist," which serves as an evaluation tool for real-time verification—ensuring that every element is addressed at every stage, from initial concept planning to final 3D modeling validation. The designer can download the pamphlet by saving the image below or by using the link provided below. Download the pamphlet


Note space

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Design Guidelines of an Inclusive Fully Autonomous Vehicle System and Interactions for Older People

by Yeongwook Shin

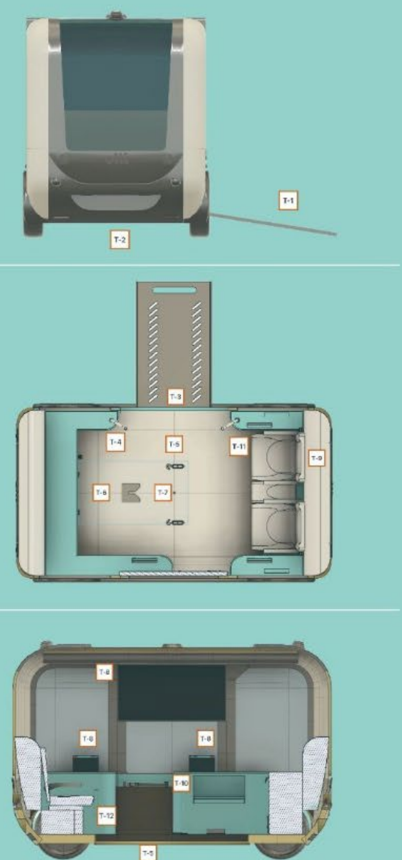
AUBURN
UNIVERSITY

INCLUSIVE
FAVs DESIGN
GUIDELINES

Make FAVs More Inclusive

Figure 87. Design Guidelines Pamphlet Front.

Vehicle



Tangible Features (Refer to Chp 4.3)

Physical Interior Components		/ 12	Personal note
Ramp	T-1	Minimum 1:4 and Max slope 1:12 based on height from ground; 600 lb capacity; 2-inch edge barriers; LED light for visible.	
FAV Kneeling System	T-2	Active suspension lowering. Adjust the floorpan height according to the ramp's length and ratio.	
Door Width	T-3	Minimum 32 inches (1220 mm) clear opening. Recommended between 34-36 inches for the large wheelchair.	
Door Handles	T-4	Low physical effort operation, 34-48 inches high; < 5 lbs force; operable with closed fist.	
Interior Routing	T-5	Other components are positioned at least 27 inches above the floor pan and do not protrude more than 4 inches for walking aid kits.	
Wheelchair Space	T-6	A single wheelchair space must be at least 36 by 48 inches. 60 inches turning diameter for wheelchairs.	
Wheelchair Securements	T-7	Automatic or Docking Securement + Manual Securement backup. Seat belt.	
Control Panel and Display	T-8	At least 15 inches from the floor and no higher than 48 inches. If there is an obstruction that protrudes more than 10 inches, the maximum height must not exceed 46 inches.	
Seat	T-9	The seat width is set at least 18 inches, and the seat for two people has at least a width of 41 inches.	
Storage and Cargo	T-10	Placed between 15 and 48 inches from the floor. Eliminates doors that might block a wheelchair. Cane and walker holder.	
Emergency Buttons	T-11	Placed between 15 and 48 inches from the floor. Well-marked and colored for quick noticing.	
Airbags	T-12	Multi-directional airbag protection for face-to-face seating.	

Size of Vehicle

W - 150 in / **H** - 98.5 in / **L** - 79.5 in

Capacity

Total 3 - **2 Passengers** & **1 Wheelchair Passenger**

Intangible Features (Refer to Chp 4.4)

Physical Interior Components	/ 8	Personal note
Task Instruction	Providing step-by-step instruction and tolerance for mistakes (See multi-modality guideline for details).	
Typography	Min. 5/8 inch character height for < 72 in. Viewing distance. Recommend San-Serif pont.	
Color & Contrast	Avoid the use of gray scale and provide color contrast at least 4.5:1 ratio. (Refer to External Sources section S-1).	
Iconography	All icons must include descriptive labels to prevent ambiguity.	
Human-Machine Interface	Check the 10 Design Insights provided in External Resources. (Refer to External Sources section S-2).	
Multi Modality	Offer various redundancy options: physical button, touch screen, and voice control. Providing redundant signals (Visual + audio ; visual + texture)	
Adaptability	Adjustable font size, interface speed, and voice volume.	
Real-time System Feedback and Transparency	Provide real-time voice and visual feedback to clearly and transparently explain the vehicle's action logic.	

Psychological and Trust-Building Factors	/ 6	Personal note
Task Instruction	Providing step-by-step instruction and tolerance for mistakes (See multi-modality guideline for details).	
Typography	Min. 5/8 inch character height for < 72 in. Viewing distance. Recommend San-Serif pont.	
Color & Contrast	Avoid the use of gray scale and provide color contrast at least 4.5:1 ratio. (Refer to External Sources section S-1).	
Iconography	All icons must include descriptive labels to prevent ambiguity.	
Human-Machine Interface	Check the 10 Design Insights provided in External Resources. (Refer to External Sources section S-2).	
Multi Modality	Offer various redundancy options: physical button, touch screen, and voice control. Providing redundant signals (Visual + audio ; visual + texture)	

Figure 88. Design Guidelines Pamphlet Back.

4.5 Conclusion

In conclusion, the realization of an inclusive FAV demands a holistic design approach that comprehensively addresses the physical, cognitive, and psychological needs of older adults and individuals with mobility impairments. Physically, interior dimensions and securement systems must strictly adhere to established anthropometric boundaries, ensuring that storage spaces fall within the optimal 15- to 48-inch reach zone. The floor plans remain unobstructed to accommodate a 60-inch wheelchair turning radius. Cognitively, digital interfaces must minimize mental workload through step-by-step UX processes, high-contrast typography, and intuitive, error-tolerant navigation frameworks. Psychologically, stigma-inducing elements must be proactively dismantled through invisible, premium design aesthetics. At the same time, trust is carefully calibrated via functional anthropomorphic features and the indispensable integration of an AVO service, which acts as a crucial socio-emotional safety net. Furthermore, the design must anticipate and comply with modernized safety regulations. By synthesizing these ergonomic, interactive, and regulatory guidelines, designers can create a deeply empathetic autonomous mobility ecosystem that champions both safety and dignified independence for vulnerable populations.

Chapter 5 Design Guideline Application

5.1 Overview

In this chapter, the author presents an inclusive FAV design as a case study, demonstrating how to create an FAV suitable for individuals with mobility impairments using the approaches and checklists introduced in Chapter 4.

5.2 Redesign Olli 2.0 to be inclusive

The original Olli 2.0 was engineered primarily for high-density public transport efficiency. However, the original layout exhibited profound accessibility gaps, particularly in independent wheelchair boarding, cognitive interface clarity, and physical securement flexibility. To resolve these accessibility challenges, the Olli 2.0 interior was redesigned by applying the guidelines established in Chapter 4. The cabin layout is divided into a designated "Passenger Side" (right of the entrance) and a "Wheelchair Side" (left of the entrance). This layout preserves a 60-inch clear central corridor, satisfying the ADA 180-degree turning radius requirements for large motorized wheelchairs.

While the original shuttle seated up to nine passengers, Waymo occupancy statistics show that over 90% of autonomous rides transport two or fewer passengers. The redesigned cabin optimizes this spatial reality by accommodating up to three passengers simultaneously: one wheelchair user and two ambulatory passengers. The interior integrates automated ramp and kneeling systems, cantilever-mounted ergonomic seating, dual-mode wheelchair securement docking, walker/cane holders, and sensory-monitored storage compartments.

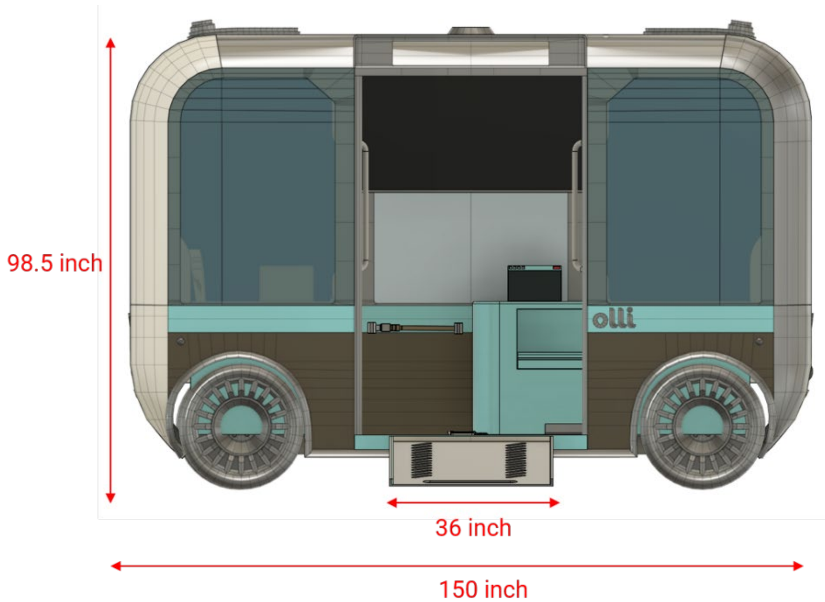


Figure 89. Olli 2.0 Side View

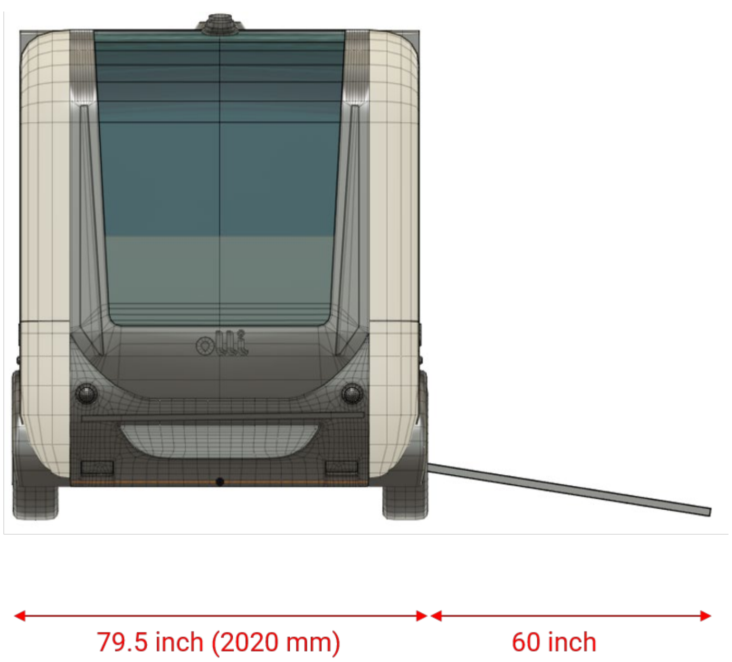


Figure 90. Olli 2.0 Front View

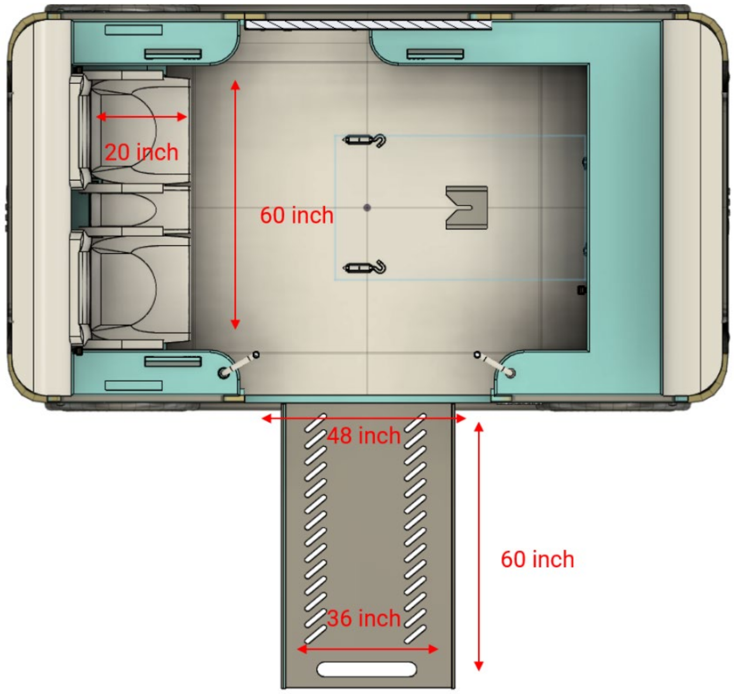


Figure 91. Olli 2.0 Top View.

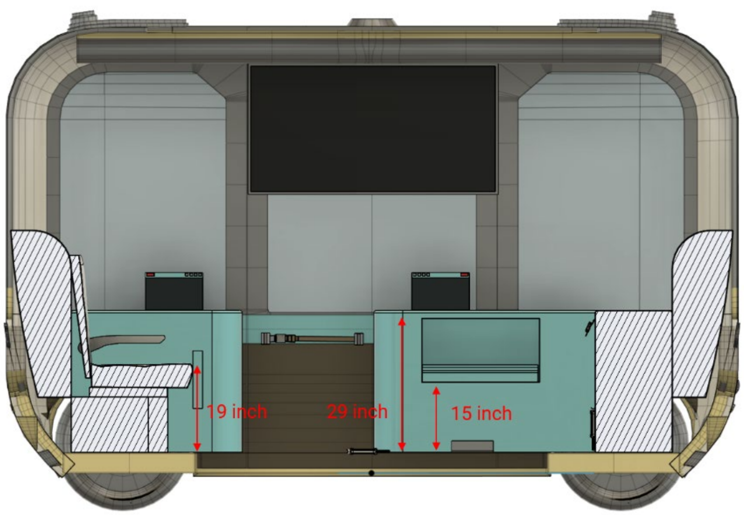


Figure 92. Olli 2.0 Top Cross-Sectional View.

5.2.1 Passenger Side

The passenger side entrance is redesigned to optimize safety and convenience for ambulatory older adults. It features an accessible mechanical manual door-open switch that remains operable during emergency power outages, alongside textured, high-contrast grab bars to assist boarding.

The seats are constructed using cantilevered, wall-mounted frames, eliminating the traditional vertical legs from the cabin floor and preventing tripping hazards for seniors with visual impairment or balance loss, while significantly increasing legroom.

Adjacent to each seat is a redundant dual-mode control panel that integrates a high-contrast capacitive touchscreen with a row of large physical tactile buttons. This configuration satisfies the Universal Design principle of Equitable Use by allowing passengers to choose their preferred interaction modality depending on their visual acuity and motor precision.

(Refer to Figure 93 for the Passenger Side Cross-Sectional View).

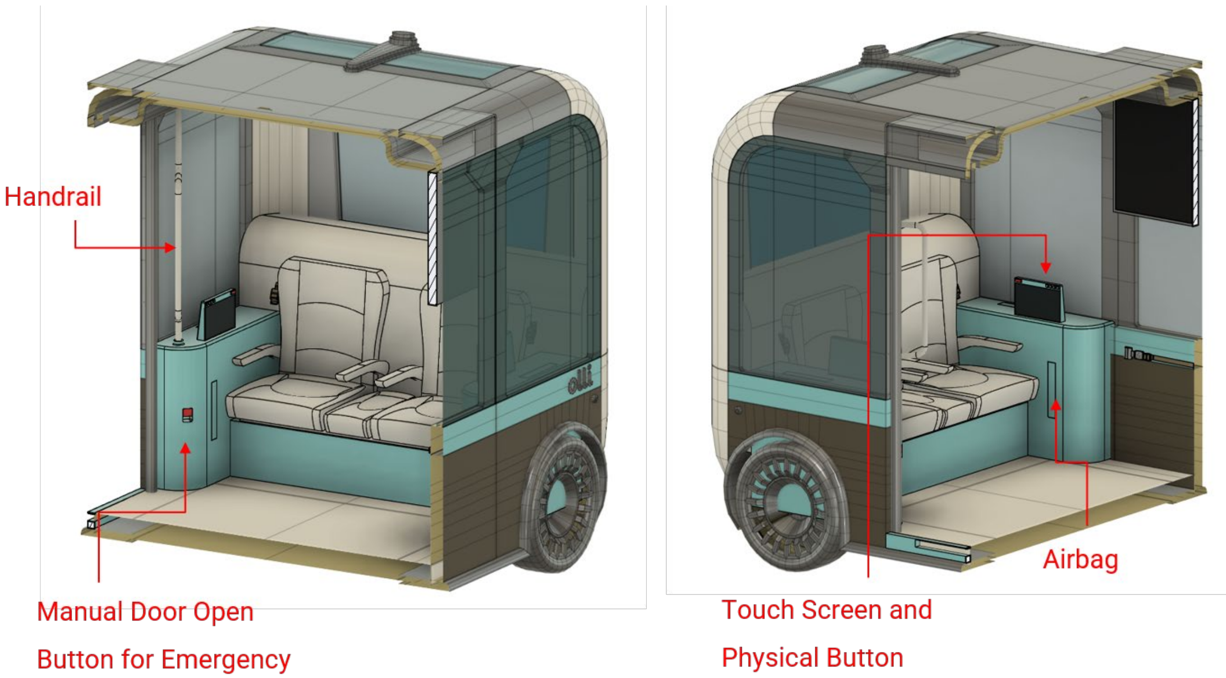


Figure 93. Passenger Side Cross-Sectional View.

Figure 94. Airbag and Emergency Door Open Features

5.2.2 Wheelchair Side

To address the social exclusion and physical reliance associated with conventional retrofitted paratransit vans, the wheelchair side features a dual-securement system. Active power wheelchair users can align with a fully automated, floor-recessed magnetic-and-mechanical docking lock, securing themselves instantly and independently without requiring operator intervention. For users with manual wheelchairs, the system provides a secondary, universal manual strap-and-hook tie-down system stowed within fold-down side panels, satisfying safety standards while preserving aesthetic integration.

A large 49-inch display is positioned directly within the wheelchair user's forward horizontal line of sight, delivering synchronized audio-visual journey notifications to prevent information loss for passengers with sensory impairments. In consistent compliance with the wheelchair reach limits identified in Chapter 4, the control touchscreens, tactile physical buttons, and dedicated storage lockers are positioned exactly 15 inches above the floor.

The storage compartments are equipped with load-cell weight sensors linked to the vehicle's HMI; if a passenger attempts to exit while personal luggage or assistive devices remain in the compartment, a proactive, multi-sensory alert is immediately issued. This closed-loop warning prevents cognitive anxiety and item loss.

(Refer to Figure 95 for the Wheelchair Side Cross-Sectional View).

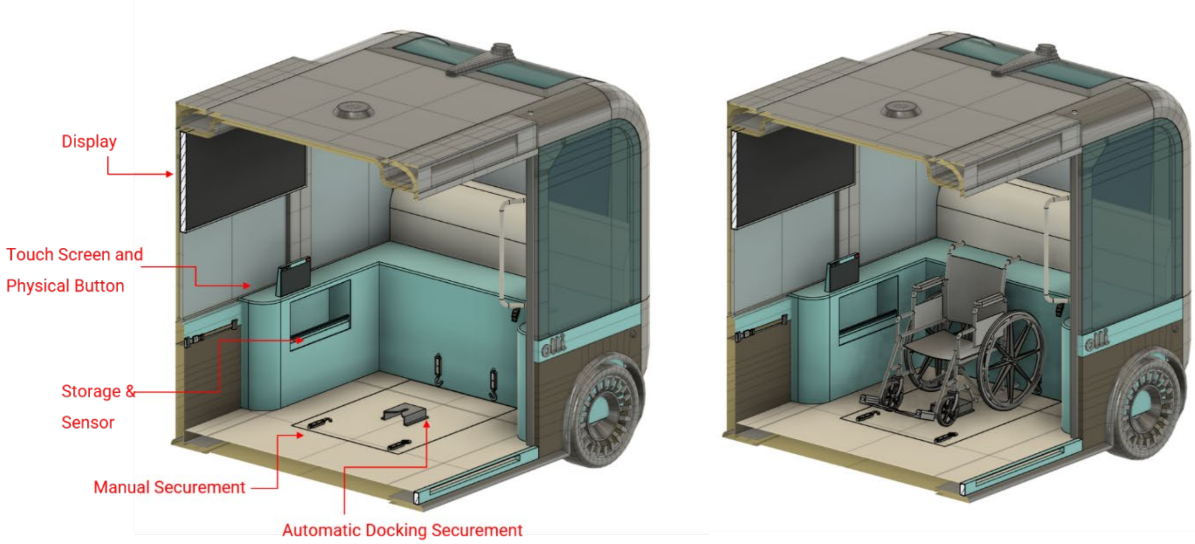


Figure 95. Wheelchair Side Cross-Sectional View.

5.2.3 Walker and Cane Holder

Directly opposite the double-wide sliding door, a dedicated walker and cane holder is integrated to prevent internal physical clutter. In conventional shared shuttles, unstructured bags and mobility devices often spill onto the floor, creating serious tripping hazards for ambulatory seniors and obstructing wheelchair casters.

Following Q'Straint mobility-aid securement specifications, this holder is installed at a refined height of 23 inches above the cabin floor, matching the natural hand reach of standing older adults. It utilizes a magnetic-assisted clamp requiring less than 5 pounds of force to latch and release, ensuring effortless manipulation for passengers suffering from arthritis or tremors. This discrete, integrated design secures devices during transit while promoting accessibility without stigma.

Figure 96. Q'Straint in vehicle walker holder (The RetroFitter, n.d.).

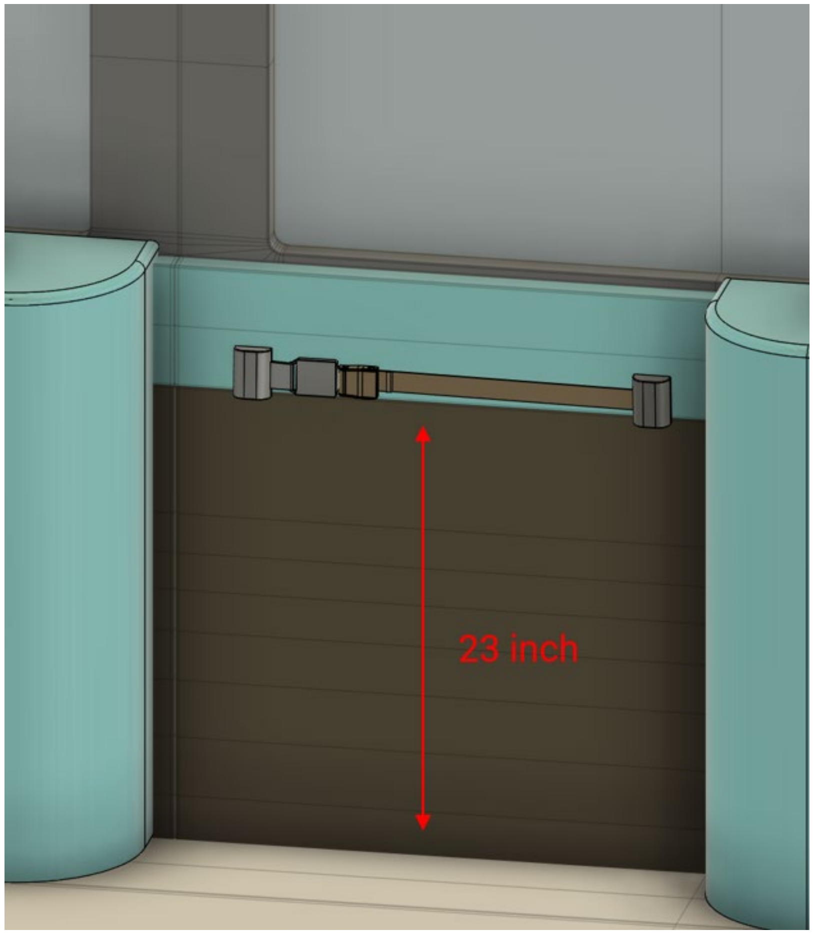


Figure 97. Walker and Cane Holder.

5.2.3 Physical control button and Touchscreen

To bridge the digital divide and alleviate technology anxiety, tactile physical buttons are seamlessly integrated directly above the capacitive touchscreen. These physical controls feature high-contrast, textured graphic icons and Braille text, providing tactile confirmation for essential functions, including door open/close commands, automated wheelchair docking activation, and volume control.

The touchscreen size is 12 by 8 inches, and each color contrast is designed to be at least 5:1. A prominent, recessed red emergency button is isolated from other controls to prevent accidental activation. When pressed, it immediately bypasses all digital system layers to establish a direct, real-time voice and video intercom with a live remote safety agency, ensuring psychological safety and immediate crisis support.

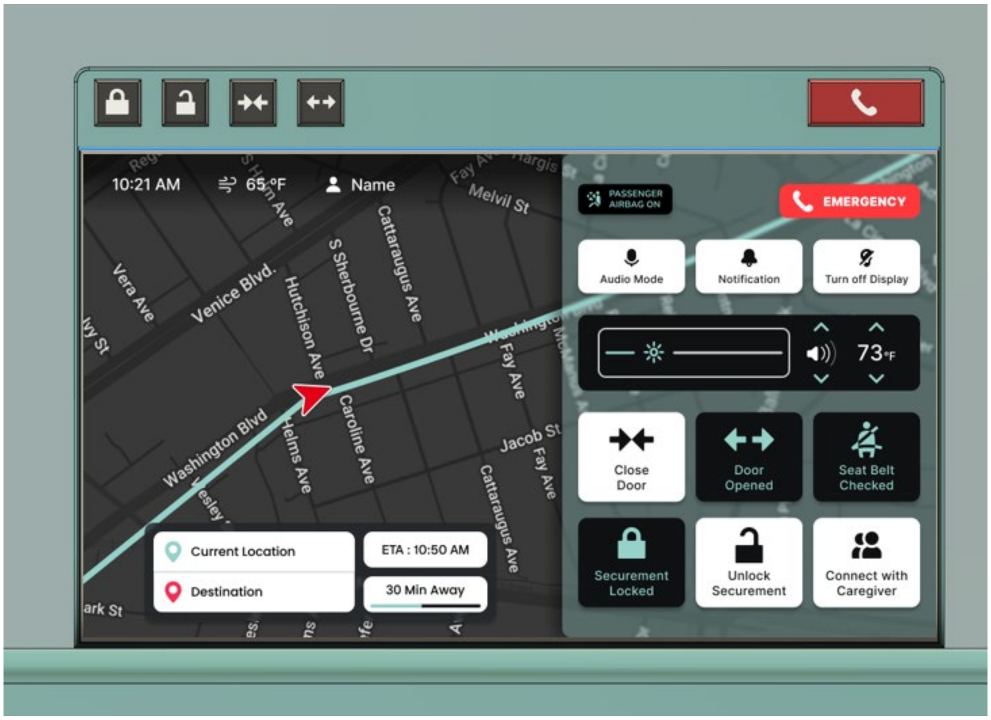


Figure 98. Physical control button and Touchscreen Interface.

5.2.4 Overview of interior space design

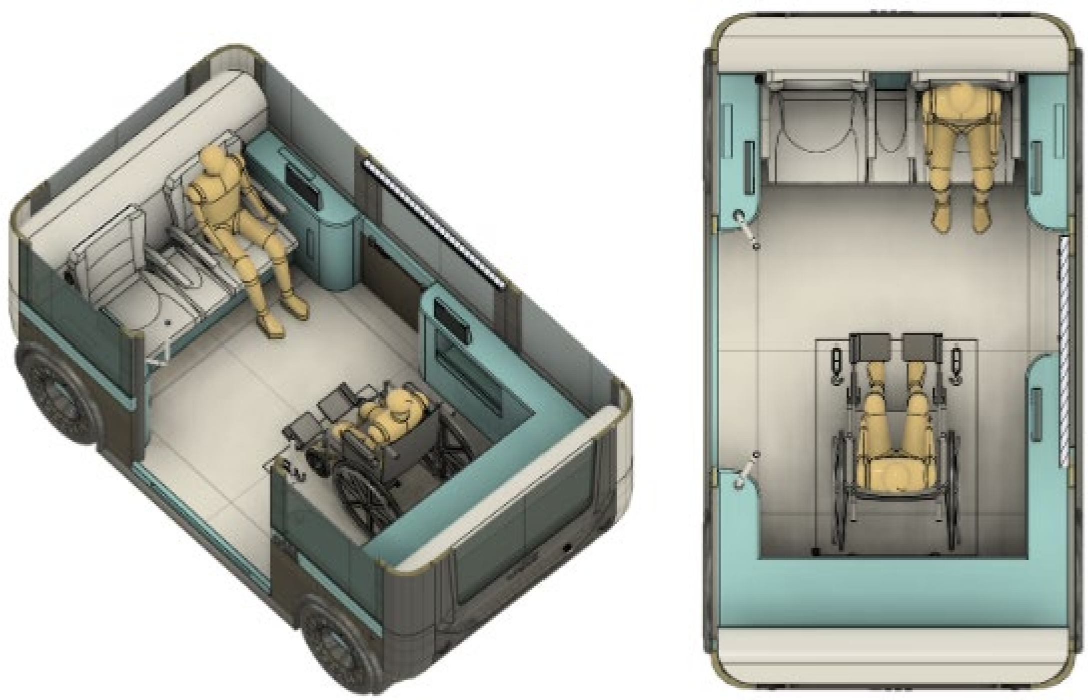


Figure 99. Overview of interior space design.

Chapter 6 Conclusion

This study explored inclusive design strategies for FAVs to accommodate users with mobility impairments and to reduce social stigmatization. By synthesizing Universal Design principles, ergonomics, and anti-stigmatization frameworks, this study redefines the future of autonomous transit as an empathetic life-support service rather than a purely technological artifact.

While this research establishes a foundational framework for inclusive vehicle architecture, several critical dimensions remain to be explored in future research. Crucially, the current study does not examine Color, Material, and Finishing (CMF) design parameters. Future research must evaluate how tactile texturization, slip-resistant polymer compounds, and precise chromatic contrast ratios (minimizing blue hues and specular glare) affect passengers with senile macular degeneration, cataracts, or sensory visual decline.

The research findings and design guidelines developed in this thesis aim to help FAV designers understand the essential factors for creating an inclusive FAV that effectively meets both the tangible and intangible needs of older people. Applying these analytical insights to the redesigned Olli 2.0 platform demonstrates that integrating multi-modal interface redundancy, dual wheelchair securement mechanics, and discrete, non-stigmatizing physical aids can restore self-efficacy and independence to older adults, successfully bridging the gap between technological capabilities and nuanced human needs.

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