

Universal Access to Autonomous Vehicle:

Universal Access Principles/Guidelines/Examples to robot taxis

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Abstract

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According to the rapid progression of self-driving technologies, self-driving taxis are expected to be commercialized and narrow the social and economic isolation of people with disabilities by offering a new means of personal transportation. However, there is a lack of research on increasing informational and physical accessibility. Especially since there is no research or design project considering the unique journey and environment that the new transportation brings. So that self-driving taxis can widely be used as transportation for people with disabilities. This paper presents eight universal access principles (four principles each in two layers: digital and physical) and detailed examples describing the principles. The eight principles build on (1) existing literature studies mainly based on the prominent universal design principles from NC State University, and (2) robot-taxi journey analysis of users with three types of disabilities (wheelchair users, blindness, and limblessness). Moreover, I have repeatedly verified and co-designed examples of the eight principles through interviews with people with disabilities. This thesis facilitates discussion of how much universal accessibility of self-driving cars is necessary and essential and leads to more research and design.

Contents

Introduction	5
Background	7
Levels of Automation	7
Being “ON-THE-LOOP”	8
Impacts of AV	8
The advent of self-driving taxis	10
Related Works	11
Research Methods	13
Findings	14
Foundation: Universal Access Principles, guidelines, and examples	14
Two touchpoints: digital and physical	15
Validation: Interviews and high-fidelity examples	16
The Principles of Universal Access to AV-Taxi	17
Four Principles	18
Guidelines & Examples	19
Conclusion	24
Reflection	25
Publish on the web: Opens a window for the principle distribution and feedback.	25
Next Challenge: A Wide Spectrum of disabilities.	25
Bibliography	26

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Introduction

Transportation "is a real game-changer" for persons with disabilities.

-by Michael Reardon, supervisory policy advisor, U.S. Department of Labor Office of Disability Employment Policy (2017)

As Reardon said, transportation is a critical infrastructure that makes visible differences in the quality of economic and social lives of people with disabilities because transportation accessibility is directly related to the financial ability and mental health of people with disabilities. Approximately one in every five people, or more than 57 million, has a disability in the United States. And more than half of the population with a disability reports their disability "severely" limits at least one functional or participatory act (Claypool et al., 2017). In other words, more than 28 million people are suffering from moving independently, like driving or using public transportation, and the number is expected to increase as the aging population accelerates.

Unfortunately, the lack of access to mobility due to disabilities is related to unemployment. "There's a lot of money being lost by the fact that people with disabilities don't have access to transportation to get to jobs. Unemployment is twice as high among the disability community." said Michael Reardon, supervisory policy advisor, U.S. Department of Labor Office of Disability Employment Policy. Moreover, *National Household Travel Survey* (NHTS) highlights accessibility features in private vehicles potentially putting them beyond the reach of the 51.4% of people aged 18 to 64 with "travel-limiting" disabilities in households with annual incomes under \$25,000. (Wiggers, 2020) Also, the relationship between accessibility to transportation and mental illness is close. Even the *Americans with Disabilities Act* (ADA) ensures the protections for accessible transportation. However, most public and private transportation remain far less than fully accessible to the disability community, often resulting in social isolation. There are approximately 3.5 million individuals who never leave their home, including 1.9 million with disabilities. Ultimately, it is to the detriment of society

that the participation and contributions of such a large segment of the population are stifled. (Claypool et al., 2017)

They need door-to-door service, not a curb-to-curb service

By Foundation for Senior Living president Tom Egan

The new personal transportation system, especially self-driving taxis, can provide door-to-door mobility services that come to the front of the house and drop them off in front of the destination. The last-minute service provided by self-driving taxis will dramatically increase the independent mobility of the disabled because they will remove the biggest obstacle to using existing public transportation independently, which were the barriers on the road. Moreover, self-driving taxis are starting to be commercialized. The most representative example is Amazon's self-driving taxi, Zoox. It began running in the California bay area in November 2020. (Joe Kukura, 2020) Self-driving cars are no longer science fiction now.

However, there is still a lack of discussion about the accessibility of self-driving taxis. If AVs are not accessible to people with disabilities (and seniors), it's going to become even worse. A report from the Minnesota Advisory Council on Connected and Autonomous Vehicles (Hietpas & Kristin, 2018), ADA Standards for Accessible Design (United States Department of Justice, 2010), and NC state university's universal design principles (Molly Follette Story et al., 1988) have been published to improve accessibility and consider the needs of people with disabilities. However, the new form of self-driving taxis, including unique experiences like calling taxis and riding a taxi on the road, is not appropriate for the environment.

This paper starts with the question, 'How can we create new universal accessibility guidelines for self-driving taxis that correspond to new contextual spatial characteristics and different types of user touch points brought by the new type of vehicle'? To investigate the above question, I have created eight accessibility guidelines with two layers, physical and digital, and practical examples covering three types of typical disabilities. The guidelines are assumed based on a self-driving taxi user journey timeline. Moreover, the guidelines were verified and developed together through repeated interviews with people with disabilities (blind, people in wheelchairs, and amputation). This paper aims to present accessibility guidelines considering the characteristics of self-driving taxis and enable future self-driving technologies and cars to be used as active transportation for disabled people so that they can benefit socially and economically.

Background

Levels of Automation

Autonomous vehicles actualize with the combination of active safety and self-driving features. Automated driving is not an all-or-nothing proposition. (Mobility Insider, 2020) The Society of Automotive Engineers (SAE) developed an industry-standard scale from zero to five levels of automation corresponding to human control vs. autonomous system control of the vehicle. (Figure 1)

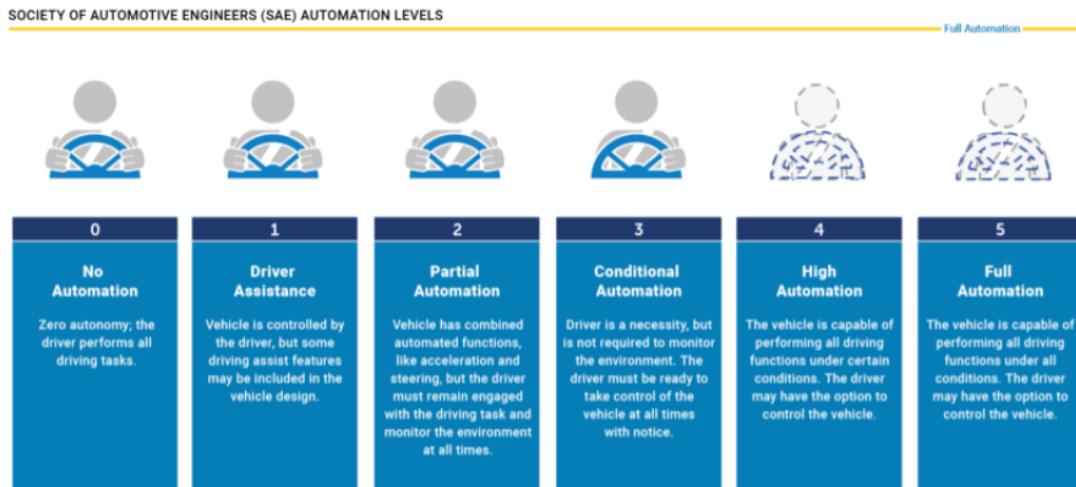


Figure 1. Automation Levels (SAE)

Here's what those levels generally mean:

- Level 0: No Automation. The driver is entirely responsible for controlling the vehicle, performing tasks like steering, braking, accelerating, or slowing down.
- Level 1: Driver Assistance. At this level, the automated systems start to take control of the vehicle in specific situations but do not fully take over.
- Level 2: Partial Automation. At this level, the vehicle can perform more complex functions that pair steering (lateral control) with acceleration and braking (longitudinal control), thanks to a greater awareness of its surroundings.
- Level 3: Conditional Automation. At Level 3, drivers can disengage from the act of driving, but only in specific situations. Conditions could be limited to certain vehicle speeds, road types, and weather conditions.
- Level 4: High Automation. At this level, the vehicle's autonomous driving system is fully capable of monitoring the driving environment and handling all driving functions for regular routes and conditions defined within its operational design domain (ODD).
- Level 5: Full Automation. No driver is required behind the wheel and might not even have a steering wheel or gas/brake pedals.

Being “ON-THE-LOOP”

In April 2021, the SAE published an update to automation level taxonomy to clarify that Levels 0-2 are “driver support features” because the driver is still heavily involved with the vehicle operation, while Levels 3-5 are “automated driving features.”

Observe, Orient, Decide, Act (OODA) loop, the concept that explains how connected a human is (or is not) to a decision-making process, is a good method to describe how human drivers act differently in levels 0-2 and 3-5. (National Research Council, 2014) A U.S. Air Force colonel originally devised the framework, and human beings “in” and “on” of the OODA loop have straightforward meanings. Missy Cummings, a former Navy fighter pilot and director of Duke University’s Humans and Autonomy Laboratory, defines “on the loop” as human supervisory control: (Figure 2) “intermittent human operator interaction with a remote, automated system to manage a controlled process or task environment.” Air traffic controllers, for example, are *on the loop* of commercial planes flying in their airspace. And thanks to increasingly sophisticated cockpit automation, most of the pilots are, too.

A human being on the loop has more potential than just convenience, especially for people with disabilities. Self-driving cars will fill visual, physical, and other disabilities and become people with disabilities hands and feet. They will be able to use personal mobility conveniently, which will increase their economic, social and cultural accessibility.

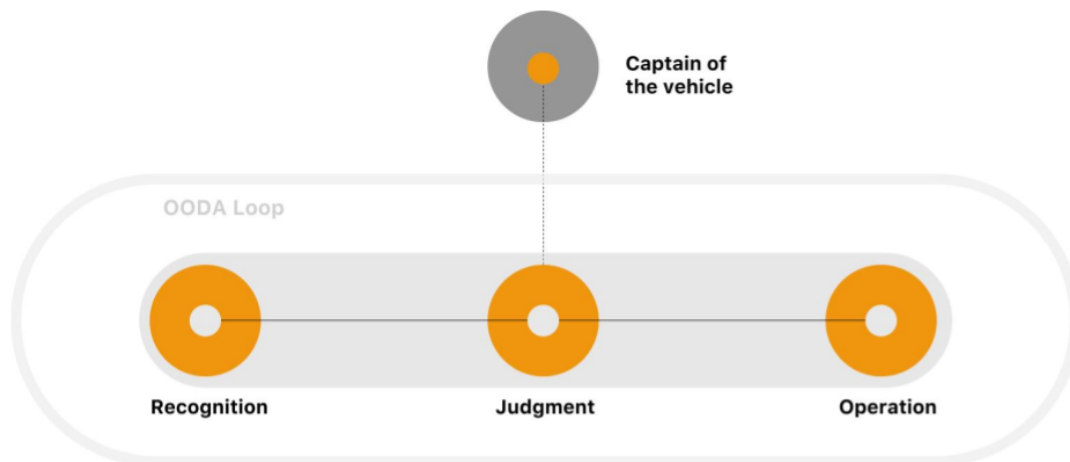


Figure 2. 'On-the-loop', OODA loop

Impacts of AV

-

"Think about your daily life, not only getting to work, getting school, out to dinner, the ability to live a high-quality life, be with peers, be with family. Being able to transport yourself is a critical fact,"

Olson, public policy director for the Minnesota Council on Disability

-

In the United States, approximately one in every five people, or more than 57 million, has a disability, and six million individuals with a disability have difficulty getting the transportation they need according to a government transport survey. (Claypool et al., 2017) When a disability limits transportation options, this can result in reduced economic opportunities, an isolation that exacerbates medical conditions or leads to depression, and a diminished quality of life.

Mitigating transportation-related obstacles for individuals with disabilities would enable new employment opportunities for approximately 2 million individuals with disabilities, and save \$19 billion annually in healthcare expenditures from missed medical appointments. This is in the context of the anticipated broader impacts of autonomous vehicles: \$1.3 trillion in savings from productivity gains, fuel costs, and accident prevention, among other sources. Transportation "is a real game-changer" for persons with disabilities, Reardon said. Without access to personal vehicles, people earn lower incomes and attain degrees at a lower rate. A 2017 report by the Ruderman Family Foundation found that autonomous vehicles (AV) could enable 2 million more people with disabilities to attain employment opportunities. (Mark Wolf, 2019) So, where are we now? The connected and automated vehicle (CAV) technology is rapidly developing. Most major manufacturers have CAV development programs: Waymo, a subsidiary of Google, began their automated vehicle program in 2009. Waymo has driven more than 10 million miles in automated mode; more than 25,000 miles each day. GM has already installed connected vehicle technology in some Cadillacs; Toyota will add connected vehicle technology to most models by 2021. The industry is moving, and it's moving fast toward the future. Many states have already passed CAV legislation to advance safety, economic development, and mobility. Nevada was the first state to pass automated vehicle legislation in 2011. Since then, 28 additional states passed laws authorizing CAV. There are over 80 connected and automated vehicle pilots across the country. (Hietpas & Kristin, 2018)

The self-driving level of individual cars is considered at level 2, and driver engagement is still necessary. (Figure 3) On the other hand, autonomous driving is becoming more widely used in large cargo, passenger, and military industries such as highway trucks and airliners. Autonomous driving levels are also higher around lv. 3-5. In airplanes, autonomous driving takes up most of the human role, with the pilot operating manually within 10 minutes of the total flight time. Assuming that it is after high-resolution mapping, shared self-driving cars will also soon replace the role of drivers. Amazon's self-driving vehicle company, Zoox, is taking the wraps off of its first robotaxi in December 2020. The company plans to launch an app-based ridesharing service. Its first target markets will be San Francisco and Las Vegas.



Figure 3. Trends in AV industry

The advent of self-driving taxis

In line with the marketization of self-driving cars, the trend for personal car ownership is also changing. That is because robot taxi services and shared vehicles cover the pros and cons of owning a private car. As you can see in the table below, car ownership rates in big cities such as Seattle and Detroit are falling. The more developed cities, the higher cost of owning cars, such as parking and insurance costs, traffic jams, and more alternative public transportation. On the other hand, more than 54% of individual car owners who are not to give up their cars said it was because of the convenience of traveling freely at any time and any place they want.

Robot taxis can be excellent transportation to increase individual mobility. They reduce time and space constraints and do not have to pay for vehicle maintenance such as parking and insurance. In particular, it has more significant potential as a means of personal transportation for disabled people who had physical and mental restrictions on driving their own vehicles. However, research on accessibility for people with disabilities to robot taxis is lacking. (Peter Welch, 2018)

With the development of self-driving technology, the role of drivers is changing, and the trend of owning private cars is changing. In these trends, the major personal transportation is mostly likely to be self-driving taxis. According to a survey from National Automobile Dealers Association (NADA) in 2018, 54% of individual vehicle owners said they own their personal cars because of the freedom to ride at any time and place they want. (Peter Welch, 2018) Self-driving taxis are likely to be a future means of personal transportation because they can provide door-to-door services without incurring maintenance costs such as parking and insurance fees while having such degrees of freedom.

Related Works

I investigated the relevant literature research with keywords for self-driving cars, accessibility, universal design, and self-driving taxis. In general, since self-driving taxi technology has not yet been fully commercialized, there has been significantly less literature on self-driving taxis, but three meaningful related literature can be found as follows.

- Accessibility: a changing paradigm towards "mobility for all" by Fédération Internationale de l'Automobile (FiA) (FiA, 2011)
It does not deal with the special environment of self-driving cars but deals with how existing universal design principles can be applied to transportation. Specific and realistic examples were presented along with photographs, giving great structural hints in establishing universal accessibility principles. In particular, I saw the possibility that the seven universal design principles from NC state univ (Molly Follette Story et al., 1988), which are currently most commonly used in the field of universal design, can also be applied to accessibility principles to transportation.
- Accessible Personal Transportation for People with Disabilities Using Autonomous Vehicles by Sashank Allu. et al. (Allu et al., 2017)
Although it did not consider the unique appearance of self-driving taxis, it presents specific figures and numbers for accessibility. For example, it contains specific numbers on how much space must be at least required inside of the car for wheelchair riding.
- Autonomous Taxi Service Design and User Experience by Sangwon Kim. et al. (2019) (Kim et al., 2019)
The most similar study to this paper. It discusses self-driving taxi services and the unique end-to-end user journey. But the internal and external appearance of self-driving taxis is still not different from typical taxis, so there is a lack of consideration for new technologies and possibilities with the new shape of taxis.

In summary, there are studies on accessibility to transportation for people with disabilities, and papers on self-driving cars are emerging, but there has not been much research on self-driving taxis and accessibility. In particular, it has been shown that there is a lack of consideration for the unique user journey and advanced technologies that self-driving taxis will bring. Thus, in this work, I consider both digital and physical touchpoints when calling taxis and riding taxis and pay attention to the internal and external appearances of taxis that will change with advances in autonomous driving technology.

There were countless design projects with keywords of universal design, interface, accessibility, and wayfinding. In particular, the following three projects are interface improvement design projects targeting different human senses and disabilities.

- **HARMAN : Creating the Future of Autonomous Car Interfaces** by Ross Rybalov (Ross Rybalov, 2018)
Display that can maximize touch screen and hand gesture interface inside the self-driving car. It is a display design that allows drivers or passengers who will play only a simple role as observers in self-driving cars to intuitively communicate with machines using a touch screen.
- **The Third Eye: A tangible interface to help visually impaired people navigate** by Jerry Yao (Jerry Yao, 2020)
Tools to print out the vision as tactile information. It allows visually impaired people to perceive visual information by touch so that they can recognize the surrounding environment.
- **2C3D: Tactile Camera For The Blinds** by Oren Geva, Asia Design Prize 2018 Winner (Oren Geva, 2018, p. 3)
A wearable device that informs visual information by touch and sound. The design in the form of glasses sensitively recognizes directional information and informs perceived environmental information by vibration and sound to help visually impaired people find their way.

In summary, similar to the above literature studies, the unique vehicle design that autonomous vehicles will bring and the design cases considering the changes in passengers' behavior were hard to find. In particular, there were many design projects dealing with only one disability, but it was difficult to find design principles that covered various disabilities. However, with the above design examples, possible interface methods could be identified, as shown in the table below.

(Figure 4) Representing three missing human senses: visual, auditory, and tactile, were able to find out which interface was appropriate through the design examples above.

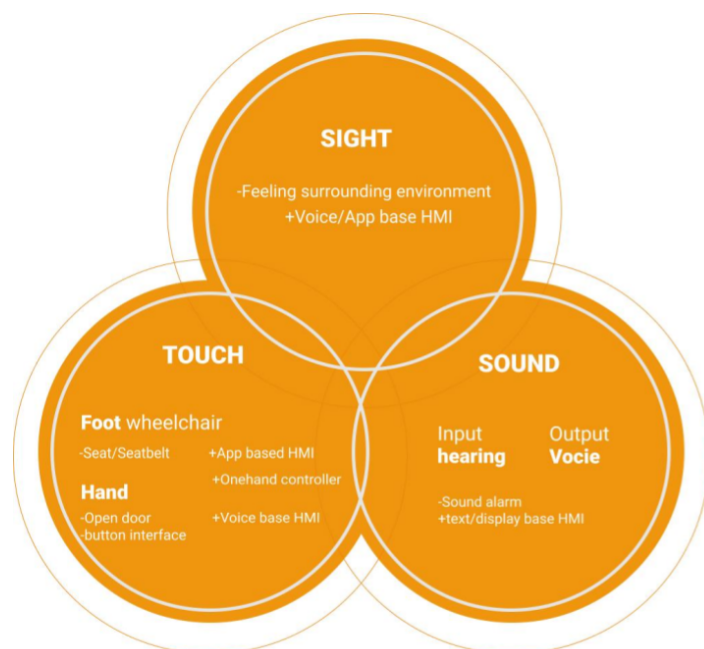


Figure 4. Three main disabilities and interfaces

Research Methods

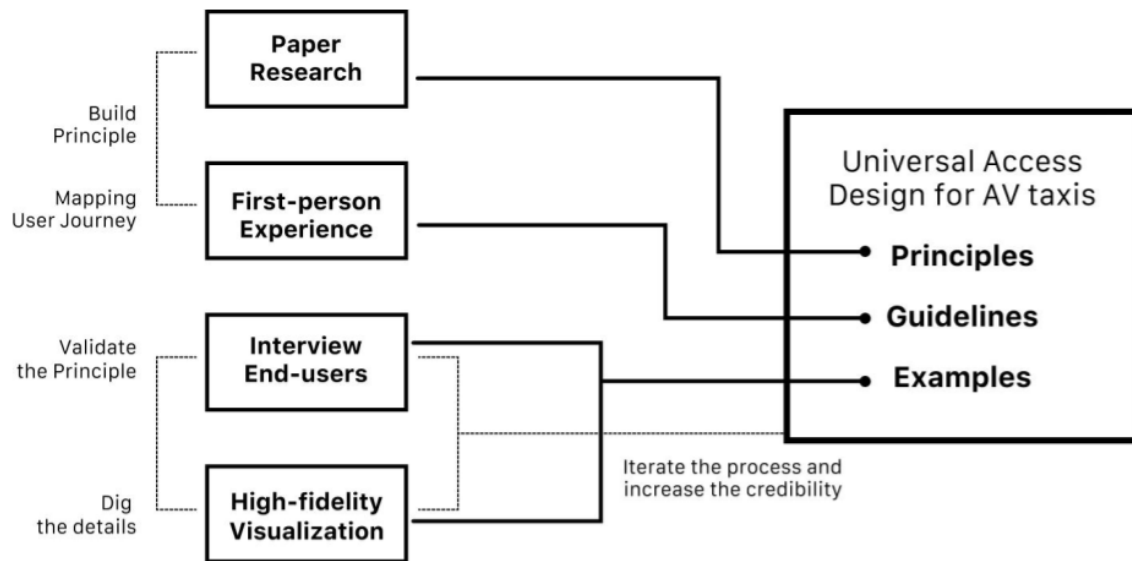


Table 1. Research Methods and Loadmap

I used four methods: paper research, first-person experience, user interview, and high fidelity visualization, to create persuasive and effective universal access principles, guidelines, and examples for robot taxis, which are not yet widely published. (Table 1) First, through the research of existing papers, I have paved the way for a general framework and content of universal access principles. The seven universal principles of NC state univ have become a significant foundation. Through the first-person experience, I map touchpoints to which universal principles can enter according to the timeline in different disabled environments such as using a wheelchair, lots of luggage, blind, etc. As a result, I found a unique timeline-oriented structure and two media (mobile and taxi) different from existing universal principles. I proved and developed the universal principle that I established by repeating visualization and interviews. Although there were difficulties in having real-person experience and feedback due to the Covid 19 and the unusual technology of robot taxis, interviewers can give me considerable feedback with high-definition 3D modeled examples.

Findings

Foundation: Universal Access Principles, guidelines, and examples

Before creating the Universal Access Principle, I conducted paper research on what layouts of principles could effectively work. I used the seven universal principles (Molly Follette Story et al., 1988) as my primary structural foundation. The seven universal design principles are the first formulated universal design principle from NC State University in 1988, and it is still predominantly used in all design areas. The top layer of the principles consists of seven keywords like you can see in figure 5 (Figure 5). There are four to five guidelines on the second layer composed of one or two sentences, and at the lowest layer, specific examples of their application.

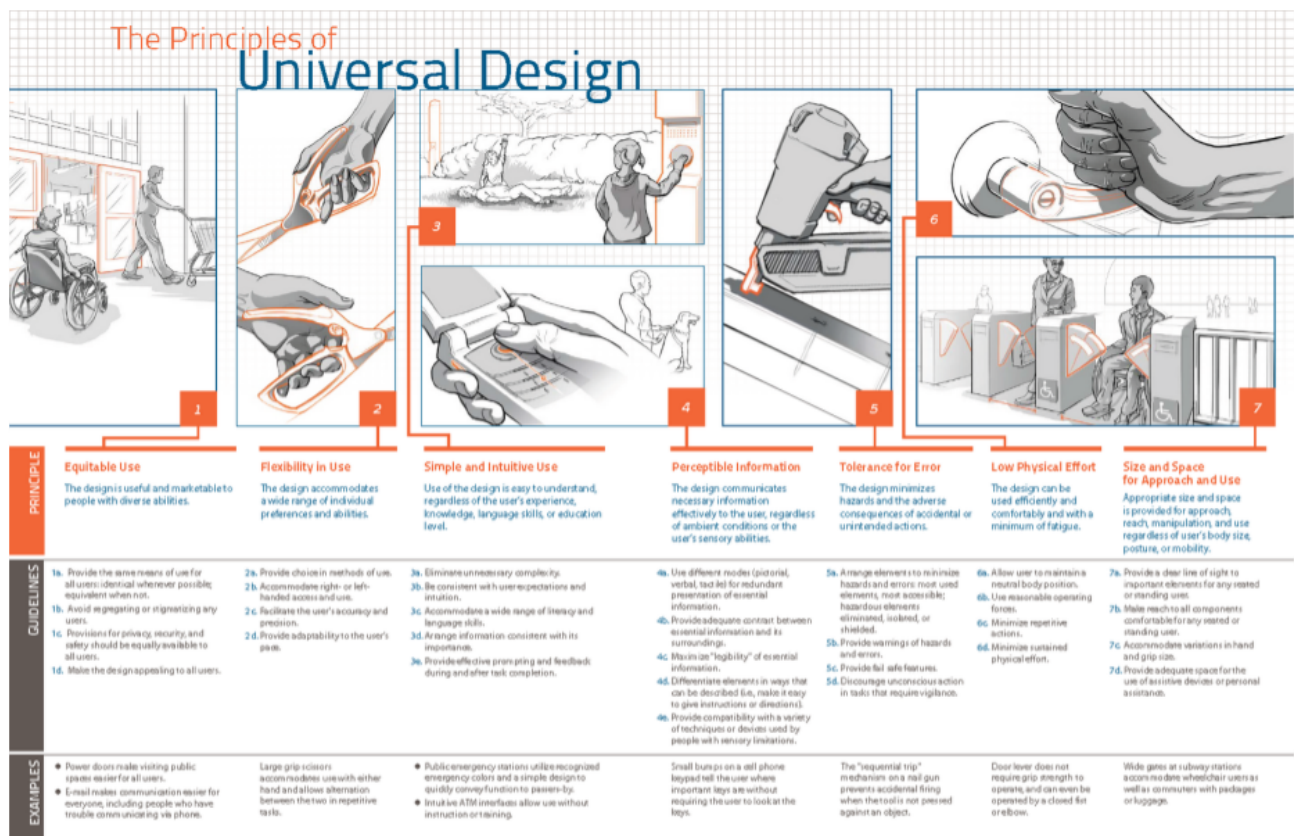


Figure 5. The seven principles of Universal Design, NC State Univ

In the figure 6 (Figure 6), the principles start with abstract concepts such as dots (principles), adding explanations with sentences (guidelines), and presenting concrete objects (examples). The advantage of this structure is that it provides broad principles and understandings applicable to various situations while also providing specific applications.

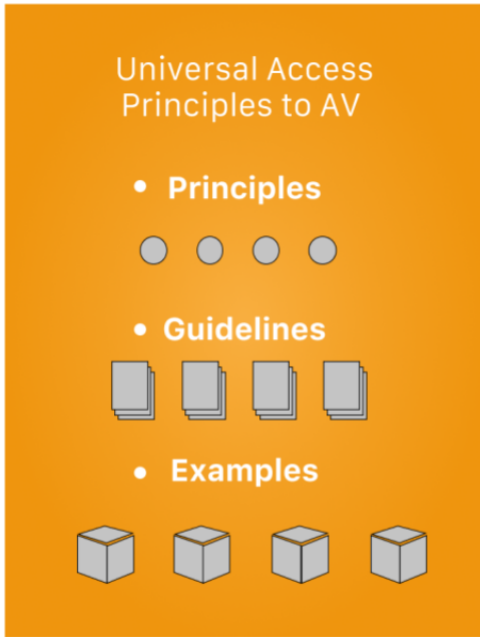


Figure 6. Universal Access Principle Structure

This structure will allow users of Universal Accessibility Principles to flexibly respond to various types of car or taxi services coming up in the future while simultaneously providing a deep understanding of how the principles apply to self-driving taxi services. Under those expectations, the Universal Access Principle consisted of four principles, two-layer guidelines, and examples.

Two touchpoints: digital and physical

The unique feature of this study, which differs from the existing Universal Design Principles, is to recognize that there are two touch points during the self-driving taxi journey and cover all. This was learned through the first-person journey experience. As shown below (Figure 7), I experienced the process of calling and riding a self-driving taxi by myself, embracing visual, tactile, and auditory disabilities.

The three senses, visual, tactile, and auditory, are the senses that people usually use to communicate with machines and the missing senses (disability) I focus on. After the above journey, unique touchpoints and pain points for each disability are described like the table below. (Table 2) The horizontal axis of the journey map is a timeline from calling taxis with digital devices to getting on and off taxis. Therefore this new transportation should be accessible with both mobile phones and taxi environments.

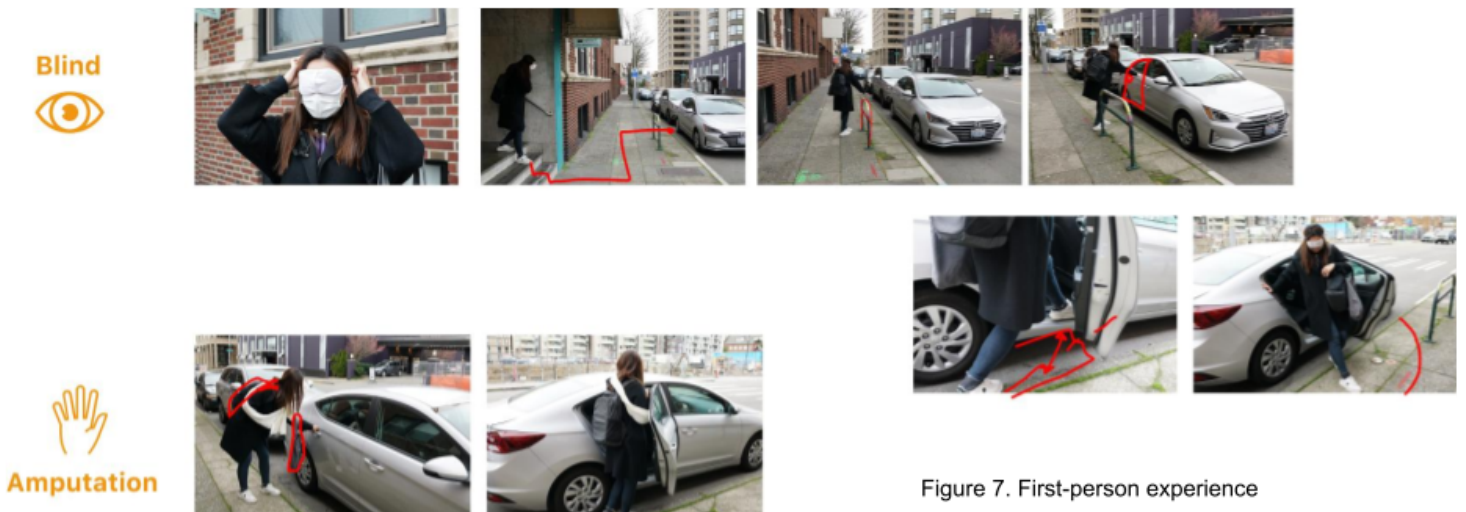


Figure 7. First-person experience

Stage	Digital Product			On the Road				In Car				On the Road		
	Call Taxi	Set Navi	Arrive/Alarm	Find Car	Car Door	Open Door	Seat	Seat Belt	Arriving Alarm	Take off	Find the entrance			
Pain points Visually impaired	How to open App and set navigation		Barrier on sidewalk	Barrier on sidewalk	Gap btw sidewalk & Car	Find car door	Where is interface screen		Gap btw sidewalk & Car		Barrier on sidewalk			
Touch Points	Phone call, Voice assistant, special devices with touch sensor	walking stick Braille blocks		touch		Buttons, App touch screen		walking stick Braille blocks						
Possible HMI				Hardkeys, buttons controllers		speech recognition proximity sensing	gesture recognition							
Pain points Wheelchair			Barrier on sidewalk	Barrier on sidewalk	Gap btw sidewalk & Car		How to place on seat and fasten seatbelt		Gap btw sidewalk & Car		Barrier on sidewalk			
Touch Points	App, Phone call, Voice assistant													
Possible HMI						Hardkeys, buttons one hand controllers speech recognition	augmented reality free-form display eye tracking							
Pain points People with limb difference	How to open App and set navigation					Open car door	how to use car HMI		Open car door					
Touch Points	Phone call, Voice assistant													
Possible HMI						speech recognition Hardkeys, buttons	augmented reality free-form display eye tracking							

Table 2. User Journey Map & Pain points

Validation: Interviews and high-fidelity examples

I repeat interviews and visualizations to verify the draft of principles and examples formulated by the above process. Since self-driving taxis have not yet been actively commercialized, it was challenging to find self-driving taxi users who can verify universal accessibility principles. Moreover, it was a big challenge to make interviewees feel the reality because the Covid-19 made it challenging to create prototype models and provide experience for interviewees.

Five interviewees with three disabilities (blind, wheelchair user, and arm amputator) participated in the interview remotely, and the discussion was repeated two to three times with each interviewee. I showed sketches and high-definition 3D renderings so that interviewees could feel reality and give critical feedback. As shown in the image below (figure 8), each meeting could validate and establish accessible taxi designs for all by accepting critical comments on the proposed design examples.

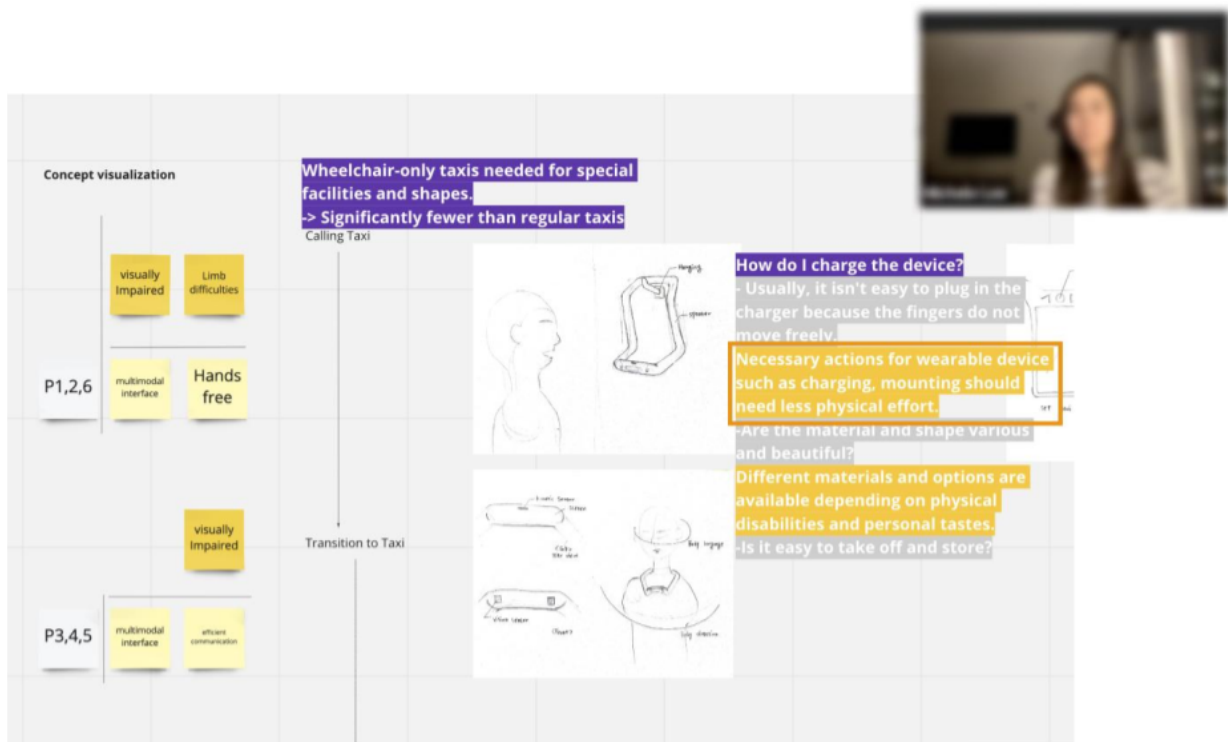


Figure 8. Interview example

The Principles of Universal Access to AV-Taxi

The Principles of Universal Access to AV-taxi		 3.T	 4.T
	 1.T	 2.T	
Principles	1. EQUALITY The original design is useful and marketable to everybody including people with diverse abilities.	2. SIMPLICITY Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.	3. EFFICIENCY The design can be used efficiently and comfortably and with a minimum of fatigue
[D] Digital Informational Mobile device	FLEXIBILITY IN USE The design and information the device deliver accommodates a wide range of individual preferences and abilities. D/1.1. Make the design appealing to all individual users regardless of whether or not having a disability. D/1.2. Avoid informatic and morphologic segregating or stigmatizing any users. D/1.3. Provide flexible modes of interactions (pictorial, verbal, tactile) and accommodate a wide range of literacy and language skills. D/1.4. Make provisions for privacy, security, and safety equally available to all users during the use of device.	PERCEPTIBLE INFORMATION The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities. D/2.1. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions). D/2.2. Arrange information consistent with its importance considering users' environment and situation change. D/2.3. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.	4. CONTINUITY The design can be used efficiently and comfortably and with a minimum of fatigue OPTIMIZED INFORMATION The design personalizes and optimizes the information required for each stage and person. D/3.1. Arrange information to maximize efficiency and minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded. D/3.2. Minimize repetitive actions. D/3.3. Provide adaptability to the user's pace. D/3.4. Provide effective prompting and feedback during and after task completion.
[T] Tangible Physical Vehicle	INCLUSIVE SIZE AND SPACE Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility. T/1.1. Provide the same transportation and the same range of usage from device for all users T/1.2. Make provisions for privacy, security, and safety equally available to all users in the space. T/1.3. Accommodate right- or left-handed access and use. T/1.4. Provide adequate space for the use of assistive devices or personal assistance. T/1.5. Accommodate variations in hand and grip size.	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. T/2.1. Eliminate unnecessary complexity. T/2.2. Be consistent with user expectations and intuition. T/2.3. Arrange information consistent with its importance considering users' environment and situation change. T/2.4. Facilitate the user's accuracy and precision.	SMOOTH MULTIPLE JOURNEYS The design considers how to reduce user workload in the continuous or regular journey D/4.1. Open communication channel between user and machine to respond to occurring errors during transition. D/4.2. Provide option to save users' personal preference such as interaction channel, language, etc., and continuously support it. TOLERANCE FOR ERROR The design minimizes hazards and the adverse consequences of accidental or unintended actions. T/3.1. Provide warnings of hazards and errors. T/3.2. Provide fail safe features. T/3.3. Discourage unconscious action in tasks that require vigilance. T/3.4. Provide a clear line of sight to important elements for any seated or standing user. LOW PHYSICAL EFFORT The design can be used efficiently and comfortably and with a minimum of fatigue T/4.1. Allow user to maintain a neutral body position and minimize sustained physical effort. T/4.2. Reduce user fatigue by utilizing the machine's power source as much as possible. T/4.3. Make reach to all components comfortable for any seated or standing user. T/4.4. Make efforts to reduce users' behavior on the machine side before requiring the user's movements.

Table 3. Universal Access Principles to AV-taxi

The Universal Accessibility Principle makes self-driving taxis, a new means of personal transportation that will be brought by developing self-driving car technology, available to people with disabilities. This principle has four principles, guidelines under two digital and physical touchpoints of each principle, and examples explaining the application of guidelines. The principle consists of four keywords as below. (table 3)

Four Principles

- **EQUALITY:** The original design is useful and marketable to everybody including people with diverse abilities.

This keyword is the most important value to consider. For example, self-driving taxis are designed to use the same taxi as ordinary users even though passengers have guide dogs and wheelchairs. So that passengers with disabilities can use the same number of taxis.

- **SIMPLICITY:** Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
- **EFFICIENCY:** The design can be used efficiently and comfortably and with a minimum of fatigue

These two keywords are closely linked. For example, a mobile screen with a simple and straightforward task enables users to communicate efficiently with the machine entity. In addition, it is easier to apply supportive interfaces such as voice assistants.

- **CONTINUITY:** The design can be used efficiently and comfortably and with a minimum of fatigue

Taxi use should be considered repeat journeys because AV taxis are intended to replace personal transportation. All personal settings should be saved and make passengers more convenient to ride the cab for their subsequent use.

Guidelines & Examples

Guidelines and examples illustrate Universal Access Principles having abstract and broad meaning in narrower perspectives and specific applications. Each keyword has a digital and tangible perspective and has its guidelines underneath the two perspectives—the guidelines number in the form like "D/1.1". In front of the slash, alphabets mean "D: digital" and "T: tangible," and numbers after the slash indicate principle number, and the following numbers indicate guideline numbers.

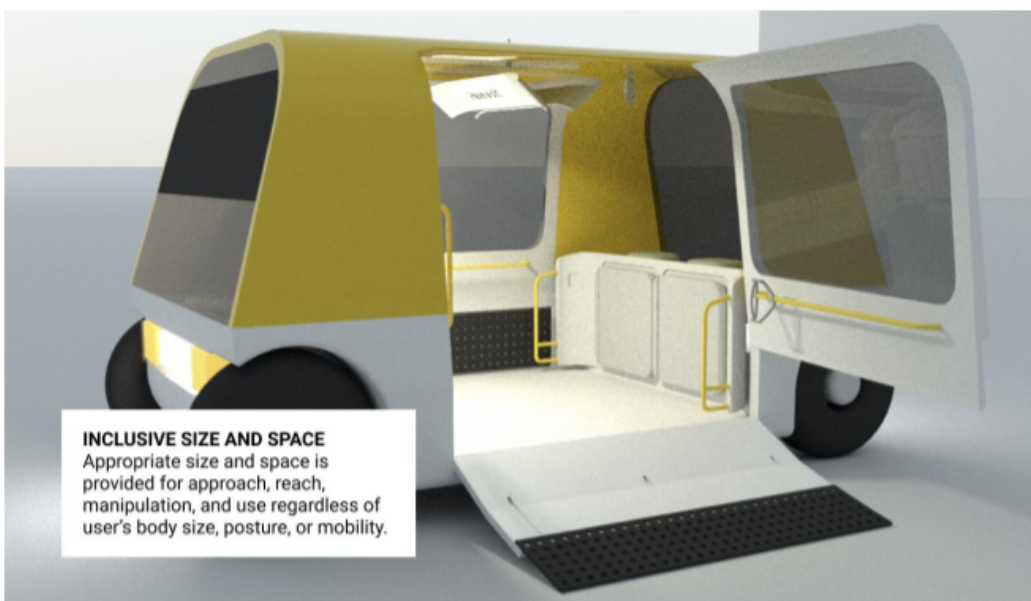
- Equality

Digital-Mobile Device	Tangible-AV Taxi
FLEXIBILITY IN USE The design and information the device deliver accommodate a wide range of individual preferences and abilities.	INCLUSIVE SIZE AND SPACE Appropriate size and space are provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.
D/1.1. Make the design appealing to all individual users regardless of whether or not having a disability. D/1.2. Avoid informatic and morphologic segregating or stigmatizing any users. D/1.3. Provide flexible modes of interactions (pictorial, verbal, tactile) and accommodate a wide range of literacy and language skills. D/1.4. Make provisions for privacy, security, and safety equally available to all users during the use of device.	T/1.1. Provide the same transportation and the same range of usage from device for all users T/1.2. Make provisions for privacy, security, and safety equally available to all users in the space. T/1.3. Accommodate right- or left-handed access and use. T/1.4. Provide adequate space for the use of assistive devices or personal assistance. T/1.5. Accommodate variations in hand and grip size.

Table 4. "Equality" guidelines

As shown in the table below (table 4), increasing equality in mobile devices provides flexible usability to use mobile devices no matter what disability you are having. The most representative example is mobile use with three supportive interfaces: touch, vision, and hearing.

Equality in taxis provides adequate space for embracing everyone and assisting devices such as scooters, guide dogs, and wheelchairs. It's a lot more than just a comfortable ride. If people with disabilities use the same taxi as common people, their time and space constraints are drastically reduced. For example, previously, a limited number of wheelchair-able taxis were only possible for people in wheelchairs even though riding taxis at the desired time and place was not a big challenge for normal passengers.



FLEXIBILITY IN USE
 The design and information the device deliver accommodates a wide range of individual preferences and abilities.

Figure 9. "Equality" Examples

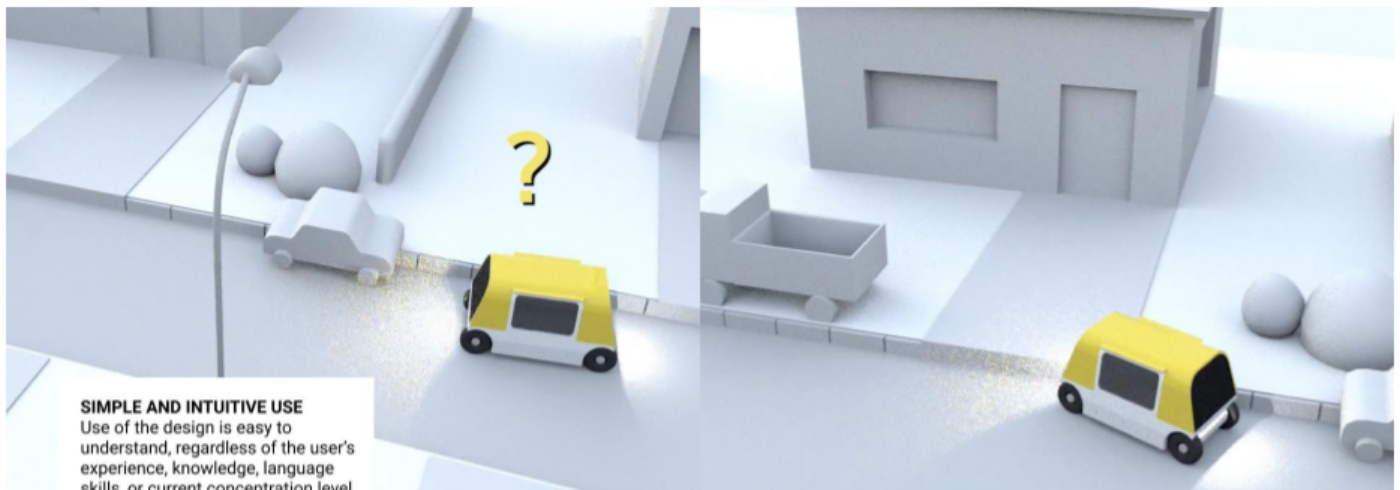
- **Simplicity**

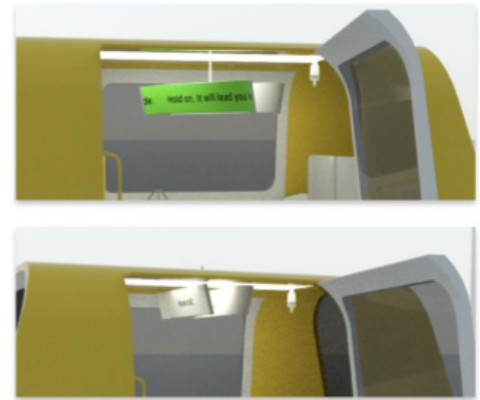
Digital-Mobile Device	Tangible-AV Taxi
PERCEPTIBLE INFORMATION The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.	SIMPLE AND INTUITIVE USE Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
D/2.1. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions). D/2.2. Arrange information consistent with its importance considering users' environment and situation change. D/2.3. Provide compatibility with a variety of techniques or devices used by people with sensory limitations.	T/2.1. Eliminate unnecessary complexity. T/2.2. Be consistent with user expectations and intuition. T/2.2. Arrange information consistent with its importance considering users' environment and situation change. T/2.3. Facilitate the user's accuracy and precision.

Table 5. "Simplicity" Guidelines

Applying simplicity on mobile devices enables users to acquire the necessary information and achieve their goals independently, no matter their knowledge of technology. To explain, as shown in the picture below (figure 10), finding a taxi when the taxi is not in front of the starting location is a big challenge for visually impaired people. In such cases, the AV taxi recognizes the passenger's location and surrounding environment with vision sensors and moves to the passenger's most accessible location. In the process, passengers will be able to skip the directional information needed to find a taxi. Only notification is needed that the taxi has stopped at the appropriate place.

The goal of simplicity is to reduce the information that passengers need to know using the advanced technology of self-driving and increase passengers' taxi accessibility. A simplicity in AV taxis is defined as providing the information needed in a timely and cognitive manner. As shown in the figure below, the screen moves with the passenger's position and eyesight to ensure that the necessary information is recognized without missing it. Depending on the passenger's situation, the most important simple sentence will be shown in text, sound, and tactile.





PERCEPTIBLE INFORMATION
 The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities

Figure 10. "Simplicity" Examples

- Efficiency

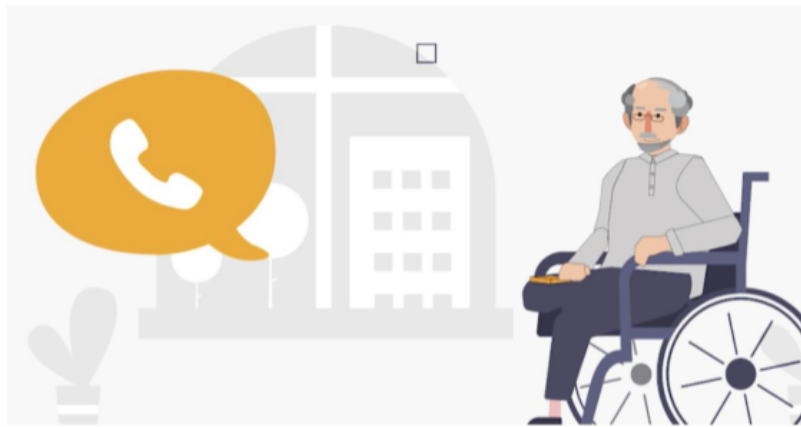
Digital-Mobile Device	Tangible-AV Taxi
OPTIMIZED INFORMATION The design personalizes and optimizes the information required for each stage and person.	TOLERANCE FOR ERROR The design minimizes hazards and the adverse consequences of accidental or unintended actions.
D/3.1. Arrange information to maximize efficiency and minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded. D/3.2. Minimize repetitive actions. D/3.3 Provide adaptability to the user's pace. D/3.4. Provide effective prompting and feedback during and after task completion.	T/3.1. Provide warnings of hazards and errors. T/3.2. Provide fail-safe features. T/3.3. Discourage unconscious action in tasks that require vigilance. T/3.4. Provide a clear line of sight to important elements for any seated or standing user.

Table 6. "Efficiency" Guidelines

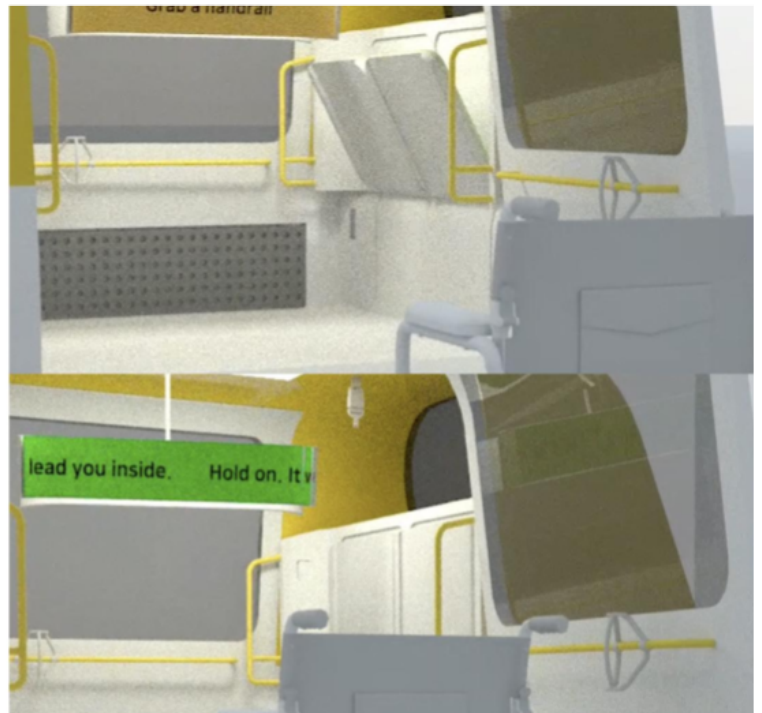
To apply Efficiency to mobile devices is to select and provide only the necessary information. Providing information may not be tied to just the form of mobile apps, but considering the most intuitive way of communicating. The figure is an example of the guideline. When a passenger waits for a taxi to arrive, a taxi will call the passenger to give enough time for the passenger to prepare, rather than making the passenger keep checking the app. Communicating the most

necessary critical information in the right situation and reducing the workload for passengers are the goal of efficiency in mobile.

The efficiency of taxis is to minimize errors and to enable taxis to respond in the event of an error. The picture below (figure 11) shows wheelchair passengers riding into the taxi through the ramp with the help of an automatic handrail. The handrail only works when the passenger holds the handrail correctly, and if the hand slips or does not hold it correctly, the rail stops working for safety, and the display in front of the passenger also says, "Hold the handle properly."



OPTIMIZED INFORMATION
The design personalizes and optimizes the information required for each stage and person.



TOLERANCE FOR ERROR
The design minimizes hazards and the adverse consequences of accidental or unintended actions.

Figure 11. "Efficiency" Examples

- Continuity

Digital-Mobile Device	Tangible-AV Taxi
SMOOTH MULTIPLE JOURNEYS The design considers how to reduce user workload in the continuous or regular journey	LOW PHYSICAL EFFORT The design can be used efficiently and comfortably and with a minimum of fatigue
D/4.1. Open communication channel between user and machine to respond to occurring errors during transition. D/4.2. Provide options to save users' personal preferences such as interaction channels, language, etc, and continuously support it.	T/4.1. Allow the user to maintain a neutral body position and minimize sustained physical effort. T/4.2. Reduce user fatigue by utilizing the machine's power source as much as possible. T/4.3. Make reach to all components comfortable for any seated or standing user. T/4.4. Make efforts to reduce users' behavior on the machine side before requiring the user's movements.

Table 7. "Continuity" Guidelines

The continuity aims to automate repeated passenger journeys setting on the phone to make them more comfortable when users ride taxis multiple times, thereby setting the personalized physical environment to reduce passengers' physical effort. The example below (figure 12) is about alternating the mobile and taxi environment together to achieve this goal. After completing the first journey, the passenger's mobile app stores both the passenger's preferred interface and vehicle environments. For example, if you were a wheelchair passenger, you would ask for a voice assistant because it is difficult to hold a cell phone while driving a wheelchair. Plus, you ask for an automated ramp and a folded seat for a wheelchair ride. All of these settings are saved after the first journey and can be recalled with a single click. This study expects self-driving taxis to be an alternative to personal transportation for people with disabilities, so smoothing the regular journey is one of the critical agendas.

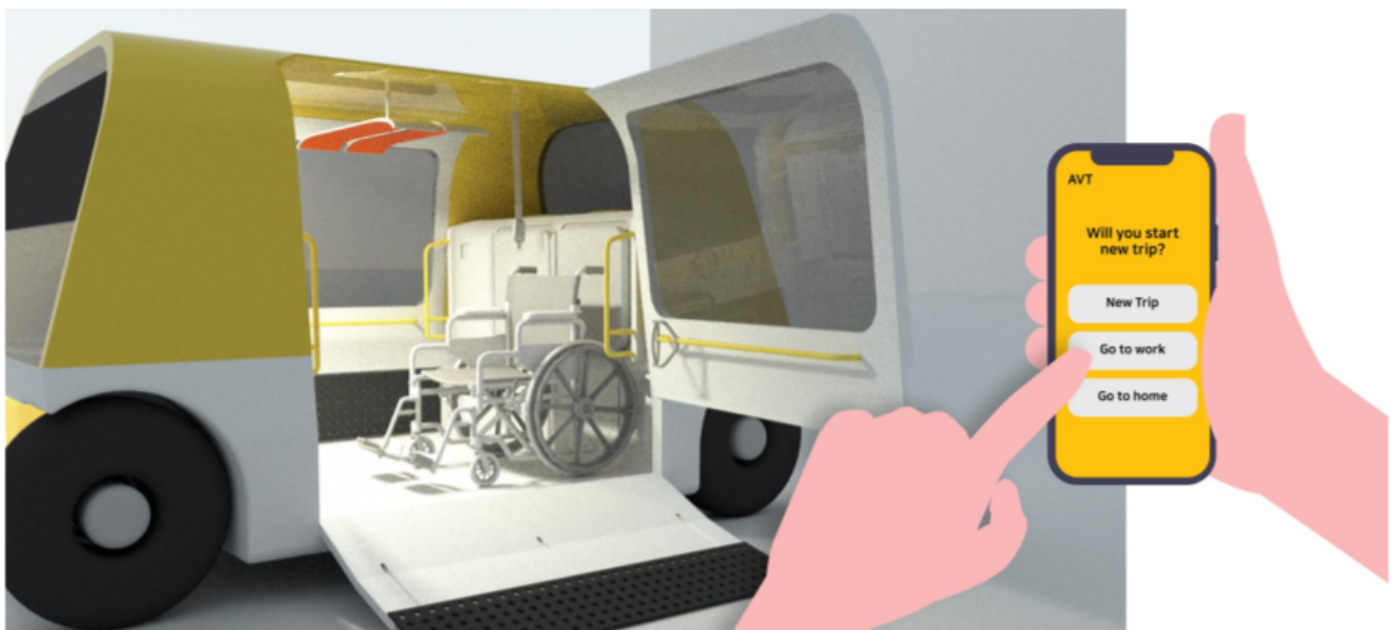


Figure 12. "Continuity" Example

Conclusion

In this paper, I propose Universal Access 4 principles accessible to everyone that will be able to future self-driving taxis. I used the seven principles of universal design (Molly Follette Story et al., 1988) to reflect on the primary format of the Universal Access Principles. I did this by doing literature research and first-person experience to understand three human senses (vision, touch, and sound): the primary three interfaces and disabilities, and unique timelines and touchpoints of self-driving taxis covered by the Universal Access Principles.

In addition, I presented the Universal Access principles, guidelines, and examples demonstrated through multiple interviews with five people with disabilities (blind, amputee, wheelchair user). Due to Covid-19 and the unusual experience of future technology, interviewers had difficulty in deeply empathizing with design principles. But through high-definition modeling, they were able to overcome it. Through deepened engagement with the unique user journey, interviewees provided critiques and insights about the design example of the Universal Access Principle.

Finally, I believe that building a universal access principle to the new transportation method, AV taxis, is an important direction that can raise more discussions around using AV taxis as the main transportation to enhance people with disabilities' mobility and life quality. It is no exaggeration to say that this paper's focus on self-driving taxis is still on the veil. So this paper was mostly made up of interviewers' critics and feedback. And the journey of proofing principles is not over yet.

Publish on the web: Opens a window for the principle distribution and feedback.

Distributing the Universal Access Principles and opening an online window for feedback is another iterative validation and development process. The more the self-driving industry becomes common and self-driving taxis are commercialized, the more realistic and accurate feedback users will be able to give.

The Universal Access principles can be downloaded [here](#).

Next Challenge: A Wide Spectrum of disabilities.

The definition of disability is very wide. There can be a variety spectrum of disabilities, including temporary disabilities caused by traffic accidents, a decline in physical capacity due to aging, and multiple disabilities, as well as genetic and permanent disabilities that we generally think of. In particular, the case of complex impairments that result in loss of complex sensory capabilities is not currently covered by the Universal Principles. "How can users access taxis when the visual and auditory interfaces are simultaneously disabled?" will be the next level of challenge.

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