Technological devices to help older people beyond the home: An inventory and assessment focusing on the neighborhood and city scales

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Abstract

What existing technological devices are available to support older people in their neighborhood and city environments as they age? Using an inventory of available and emerging technological devices, this paper finds many devices address older people's mobility and safety as pedestrians or in motorized vehicles. Fewer deal directly with physical and mental health, social connections, or other everyday activities. Emerging types of devices to address these less-common areas include robots (for delivery services and physical support), activity monitors, outdoor audio, smart streetlights, and furniture. These technologies already form a complex and dynamic landscape for older people to interact with over time. For technological devices to better help older people thrive in outdoor urban spaces, however, more work needs to be done so they can facilitate social connectedness and target the diversity of older people including those with cognitive impairments and with low incomes. Many also rely on the infrastructure of streets and sidewalks which may not be equitably distributed.

Keywords: technology; aging; smart cities; health; mobility; safety

Introduction

Around the world the population is aging, creating challenges that technologies may be able to help ameliorate. While much has been written about new technologies helping older people inside buildings such as their homes and healthcare facilities, less attention has been paid to the neighborhood and city environments they inhabit including streets, parks, and transportation. We examine new technological devices that operate outside buildings to ask what new urban-scale technological devices are available to support older people using their neighborhood and city environments as they age in place? Based on the findings, we draw implications for areas where there is potential for further development.

Examining the connection between aging and urban technological devices required several inter-related steps to identify and classify these devices. We compiled an inventory of such devices currently available and in active development that focus on assisting older people use the outdoor environment. We reviewed academic and grey literature that described and sometimes evaluated these technologies. We also adapted a typology or classification developed for technologies at the person and building scale to look more specifically at environments at the block, neighborhood, city, and metropolitan level. We used the typology to shape the inventory and then the inventory to refine the typology. We then proposed areas for new technological development.

What, however, is a new urban-scale technological device for older people? First, what is a technology? Historically, technology has been difficult to define (Hughes, 2001). It has been broadly defined as how and what things are commonly done (Hughes, 2001, p. 6852) or a "formalized practice" (Franklin, 1992, p. 15). Carroll (2017, p. 18) reviewed definitions of technology over the past hundred years, investigating the nature of technology, and developed a comprehensive definition that a technology is, in part, "inherently intelligent enough either to function, to be used to function, to be imbued with, or to be interpreted as having, a function that only intelligent beings (human or otherwise) have the ability to comprehend" [i].

In this paper we define technology in a practical sense as "the systematic application of scientific or other organized knowledge to practical tasks" (Galbraith et al., 2015, p. 14; Pacey, 1983, p. 6). A technology includes both the knowledge from which products are made and the products where knowledge is manifested (Hughes, 2001; Kaplan & Tripsas, 2008). The products can be material (e. g., a space station) and virtual (e. g., computer software) (*Technology*, n.d.). This paper addresses material products, or devices, used in outdoor spaces beyond the home. The new urban-scale technological devices include new products and those in advanced stages of development, with most having computerized components. Additionally, such technologies need to help with aging, including the physical, mental, and social changes associated with getting older. This includes some technological devices developed for the general population but that assist older people, such as delivery robots and autonomous vehicle systems. In discussing urban technological devices, we include uses in the cores of large cities as well as suburbs, small towns, and villages.

In the rest of the paper, we outline how technological devices can help older people in outdoor spaces, explain how we compiled the inventory, and list types of technologies currently available devices. We found that most technological devices relevant beyond the building enhance older people's safety and mobility by foot, wheelchair, and motorized vehicle. However, there are also robots for delivery services and physical support, air quality and activity monitors, outdoor audio equipment, smart streetlights, and smart furniture. These can serve older people's health, social connectedness, everyday activities, and leisure. While these new urban technological devices can improve the fit between older people and their environments, frequently they rely on the infrastructure of streets, sidewalks, and public spaces which may be inequitably provided. While some are relatively inexpensive, others are costly for individuals or governments. Few have been evaluated. Ultimately, we propose that such technologies form a complex landscape with opportunities to develop and coordinate technologies to better address the diverse needs of older people.

Background

Technologies, Aging, and Environments

In examining technologies to help older people as they age, it is important to define the kinds of environments and social arrangements older people experience. Though nursing facilities provide benefits for those who need substantial care, surveys and interviews demonstrate that the large majority of older adults around the world want to live in the community with or without help, as opposed to living in a nursing home (Binette, 2021; Lehnert et al., 2019; Forsyth &

Molinsky, 2021). Frequently stated reasons older people prefer to *age in place*, or continue to reside in their existing home and neighborhood, are related to the needs for personal identity, belonging, independence, control, privacy, and dignity (Lehnert et al., 2019). Thus the home, community, and wider environments need to support people as their needs change over time. In addition, environmental features such as road safety infrastructure, lighting, and crossings are among older residents' top concerns about outdoor spaces, based on a large sample survey in Germany (Brüchert et al., 2021).

Older people are diverse in age, abilities, locations, and preferences, but share some commonalities relevant to the role of technologies. As biological functions such as vision, hearing, the musculoskeletal system, and cognitive function change with aging, older people may have difficulties in getting out of their home and moving around in the community and city (Baltes, 1997; Deary et al., 2009). Technologies can help environments provide better affordances to older people, allowing them to remain dwelling in the community for longer and increasing their quality of life. Research on older adults' perspectives has shown technology is expected to improve safety and independence when aging in place, especially for those who experienced accidents like falls, though there are concerns such as cost, privacy issues, and forgetting the device (Peek et al., 2014). In motorized scenarios, a review of studies on older users' perceptions indicated that in-vehicle technologies bring various benefits to older drivers such as preventing crashes, improving reaction times, and reducing stress (Eby et al., 2016).

Research on the potential benefits of technology for aging has been thriving in recent decades since the term "gerontechnology" was coined in 1990s, though the focus has mainly been on the individual and the home (Schulz et al., 2015, p. 725). Several reviews have explored how smartphone applications, telehealth, smart homes, and social robots can help older people age at home. For example, Reeder et al. (2013) and Liu et al. (2016) both reviewed the evidence for smart homes and home-based health-monitoring technologies supporting aging in place. According to Reeder et al. (2013) the most effective technologies used multicomponent approaches including activity sensing, reminders, and other similar functions related to the individual. Liu et al. (2016) found evidence for smart homes and home-based-monitoring being useful in some areas--activities of daily living, cognitive decline, mental health, and heart conditions--but not others.

Other reviews have identified problems with technologies at the person and home scales including barriers to use and a lack of evidence of efficacy in helping people in and around the home. In a systematic review and meta-analysis Pu et al. (2019) examined the effectiveness of social robots (e. g., robotic pets) for older people. They found social robots seemed helpful for coping with agitation, anxiety, and loneliness, though results from the meta-analysis were not significant. Grossi et al. (2020) reviewed the frameworks of positive technology (PT), an emerging field combining information and communication technologies and positive psychology, assessing how to use computer vision and machine learning to promote well-being of older people. They concluded that currently available technologies do not meet potential needs. Marikyan et al. (2019) reviewed the smart home literature from a general user perspective across all ages, finding barriers related to technological fit, cost, privacy, legal issues related to health applications, lack of knowledge, and the need to change habitual behaviors to use technologies.

Some reviews have covered technologies that can be used outside homes including technologies related to mobility, monitoring, and social interaction. Blackman et al. (2016) reviewed ambient assisted living technologies for older people with some degree of cognitive impairment. These technologies allow people to live independently by "integrating sensors, actuators, smart interfaces, and artificial intelligence" (Blackman et al. 2016, 56). They identified 59 technologies, which included those that could be used outside homes such as location tracking, navigation, and transportation information. Koetteritzsch and Weyers (2016) also reviewed assistive technologies for older adults, including applications related to monitoring, therapy, reminders, navigation, and transportation services, along with multi-user applications that provide virtual communities and connect people in the same region. They proposed that assistive urban technologies need to be better integrated with each other, adapted to older adults, introduced to the market, and evaluated from a user perspective. Satariano et al. (2014) summarized technologies specifically related to aging in place. These included health information technologies, individual mobile devices, environmentally-based devices like passive sensors and assistive devices, and technologically enhanced automobiles, with the latter two engaging the neighborhood scale. A review by Shishehgar et al. (2018) focused on how robotic technology could help older people. They identified nine robot types, two of which applied to outdoors, including manipulator service robots to carry goods and rehabilitation robots such as walking assistants and intelligent wheelchairs. These reviews form an extremely useful base for the current study that updates earlier reviews and extends the more recent ones to cover the area beyond the home.

While the smart city literature has examined technologies at the urban scale, only a small part has specifically targeted older people. For example, some scholars have reviewed subdomains of smart cities such as how intelligent transportation technologies could improve mobility for older people (Eby et al., 2016; Mitchell & Suen, 1998). However, scholars have more typically examined features and composition of a smart city, technological change, social sustainability, management, and governance (Araral, 2020; Aurigi & Odendaal, 2020; Tomor et al., 2019; Silva et al., 2018; Chamoso et al., 2018).

Technologies and Life Domains

To better understand the many types of technologies and different life domains to which they apply, we adapted a taxonomy developed by Schultz et al. (2015) to the urban scale. Schultz et al. (2015) used a taxonomy to examine areas of research related to technological applications for older adults and compared these to life domains. They found that most research was in health, including telehealth and e-health. We adapted their taxonomy using the same life domains and technology functions. By classifying the devices, we propose that many potential urban-scale technologies for aging are related to mobility, safety, and to some extent everyday activities (Table 1). Several cells in Table 1 do not have examples or have examples that help indirectly. In some cases, such as diagnosis and screening, there are existing technologies, but they are used in the home or a medical setting. In the case of social connectedness, technologies can involve software such as virtual communities, which is not the focus of this paper, rather than devices, though some of the devices in other columns (e. g., mobility) can help social connectedness indirectly. This is echoed by our findings. More detail about each of the technologies is provided in the Appendix.

Table 1: Technological Devices and Important Life Domains for Older People: Potential Areas for Neighborhood and City Scale

	Life domains (across)				
Technology functions (down)	**Physical and mental health**	**Mobility**	**Social connectedness**	**Safety**	**Everyday activities and leisure**
A. Monitoring and measuring (environment, individual)	Air quality monitoring, Personal/public physical activity and health monitors, smart bus stops	Pedestrian crossing sensors, in-vehicle devices	[Indirectly via mobility and everyday activities]	Fall detectors, in-vehicle devices	Smart street furniture
B. Diagnosis and screening (identify problems, needs)	Personal/public physical activity monitors, smart bus stops	Driving simulators	*NA*	Driving simulators, fall detectors	*NA*
C. Treatment or intervention (assistance)	[Indirectly via mobility]	Smart crossing signals, pedestrian crossing sensors, wayfinding tools, robots (mobility, delivery), vehicle access, in-vehicle devices, smart bus stops, autonomous vehicles	Outdoor audio enhancement	Smart crossing signals, pedestrian crossing sensors, driving simulators, in-vehicle devices, autonomous vehicles, smart streetlights	Robots (mobility and delivery), smart street furniture

Adapted from Shultz et al. 2015, Table 1, using their life domain and technology function categories with examples added from our inventory.
NA = not in the paper because they are not at the right scale, e. g., they are at the scale of the person or the home, or involve software and apps.

Methods

In this project, we examined technological devices to address a central question: What new urban-scale technological devices are available to support older people using their neighborhood and city environments as they age in place? We intended for this review to explore the scope of existing technological devices rather than be an exhaustive discovery of all the individual devices of common types. Based on the findings, we also drew out implications for where technologies could be developed further.

We developed an inventory of urban-scale technological devices to support older people in an iterative manner. First, a preliminary inventory was compiled using academic literature, which was obtained from Web of Science and Google Scholar, searching with combinations of core concepts and variants such as urban technology, gerontechnology, aging, older people, and smart cities. Brainstorming also helped to expand the preliminary inventory.

To help further focus our search, we adapted an existing typology of technologies focused more on the individual and building scales to both identify neighborhood and urban technological devices and their associated keywords and assess areas where they would likely be developed (see Table 1). This process helped to identify any neglected areas in the inventory.

Then, we looked for existing example devices for each category in the refined inventory, including material available in English in academic literature as well as magazine articles, blogs, and product websites, searching on Web of Science, Google Scholar, and Google with keywords related to each category. This search was done by two authors and three research assistants in the United States. We used multiple team members in order to try to overcome some of the biases in Google algorithms due to personalized settings and search history (*How Search Algorithms Work*, n.d.). In the whole process, we expanded the inventory when new categories emerged. We iterated the process until we no longer found new categories. We also shared the draft paper with experts involved in developing and implementing new technologies; they indicated the typology was complete.

The Appendix summarizes the range, categories, and examples of technological devices and provides sources for trade and scholarly references. Most identified technological devices were specifically aimed at older people, though we included some for the general public that had a high potential to help older people. Finally, we do not have a financial interest in any of the firms that provide these technologies. However, after we drafted this paper, we found that a university-based collaborator initially developed one of the technologies listed (Harvard Office of Technology Development, 2016).

One limitation is that we were more likely to include example products from the US and other sources in English due to Google algorithms such as location proximity and language factors (*How Search Algorithms Work*, n.d.). Our review strategy will also have missed those technologies that are not available to the public or documented in the research literature.

Results

Most existing urban-scale technological devices for older people are related to safety and pedestrian and motorized mobility. Typical examples came from larger urban areas or wealthier locations, although many could be applied to a wider range of locations. Table 2 presents a list of the categories, functions, and life domains they serve, reflecting the typology in Table 1. In the rest of this section, we focus on three types of uses: pedestrian activities, motorized travel, and general outdoor activities. We discuss each technology in terms of its definition, intention, function or mechanism, range, and future. The description of these technological devices is based on identified example products. See the Appendix for details of the products and their references.

Table 2: Urban Technologies for Older People by Life Domain and Technology Functions

Technology types	Life domains					Technology functions		
	Physical and mental health	**Mob-ility**	**Social connect-edness**	**Safety**	**Everyday activities and leisure**	**A. Monitor-ing and measuring (individual, environ-ment)**	**B. Diagnosis and screening (identify problems, needs)**	**C. Treatment or intervention (assistance)**
Pedestrian Mobility								
Pedestrian crossing sensors		x		xx		xx		
Smart crossing signals		x		xx		xx		
Wayfinding tools		xx		xx	x			xx
Robots for mobility	xx	xx		x	x			xx
Fall detectors (outdoor)	xx			xx			xx	
Motorized Mobility and Access								
Vehicle access		xx		xx				xx
Driving simulators		xx		xx		xx	xx	xx
In-vehicle technologies		xx		xx		xx	xx	xx
Autonomous vehicles		xx		x		x		xx
Delivery vehicles and robots		xx			xx			xx
General Outdoor Activities								
Air quality measurement	xx			x		xx		
Outdoor audio enhancement			xx		xx			xx
Smart streetlights		x		xx	x	x		xx
Smart street furniture		x	x	xx	x	xx		xx
Smart bus stops		xx						xx
Public physical activity monitors	xx		x		xx	xx		xx
Personal physical activity and health monitors	xx	x		x		xx	xx	xx

XX = major focus; x = minor focus

Pedestrian Scenarios

Technological devices can help older pedestrians in multiple ways. They can assist older people with a slow gait to cross a street safely, help visually impaired people to travel by foot, provide physical support to weak pedestrians, and send out alerts when someone falls.

Pedestrian Crossing Sensors

Pedestrian crossing sensors are devices installed on a traffic or crossing light pole to detect pedestrians at the crosswalk. These sensors give extended time for slower pedestrians to finish crossing safely. Crossing a street during the regular light cycle is often challenging for people who are less mobile such as older, physically-challenged, and visually impaired people.

We identified three types of pedestrian crossing sensors based on the ways they work: manual, automated, and smartphone triggered. Manual sensors need the pedestrian to manually trigger the signal with a concession card to have longer light to cross a street. For example, the Green Man+ system has been widely implemented in Singapore. Automatic sensors automatically detect any pedestrians in the target zone and allocate additional time to allow them to exit the crosswalk. This device can also increase traffic efficiency by reducing the stop time for vehicles when no pedestrian is detected. Additionally, since the sensor is automatic, older people do not need to bring a card or remember to tap it. However, pedestrians breaking traffic rules can cause crossing times to be unnecessarily extended. Lastly, smartphone-triggered sensors respond only to people if they have installed an application on their smartphone. When the sensor detects an application user is approaching the selected crossroad, the traffic control system is triggered to give a prolonged walk light. However, it does not help people who have not installed the application.

In the future, pedestrian crossing sensors could combine positive features of the three types. Using cameras and machine learning techniques, such a device may automatically detect pedestrians and prioritize those with reduced mobility by automatically identifying their age group and mobility-aid devices such as wheelchairs, scooters, and walking frames.

Figure 1: A Green Man device in Singapore, 2019

https://commons.wikimedia.org/wiki/File:Ampel-Singapur-11-fws.jpg

Smart Crossing Signals

Smart crossing signals include devices that use different signals besides regular traffic lights to alert travelers, prioritize pedestrians, and improve road safety. An older example is the audible pedestrian signal, which provides pedestrian timing and street information. It is especially helpful for visually impaired pedestrians and has been widely used in Japan, Australia, the US, and some European countries in the past 20 years (Harkey et al., 2007).

Emerging smart crossing signals include dynamic crossings, flashing lines, and tactile pedestrian pads. Based on cameras, machine learning techniques, and LED materials, dynamic crossings monitor street traffic, identify different mode users and their trajectories, and generate dynamic LED-lit signs on the road surface. The dynamic signs can warn automobiles to stop, alert cyclists where they should wait, and signal pedestrians to cross the street. Flashing lines are electronic strips or groups of lights in front of the traditional zebra crossings that are triggered when someone crosses the street and glow red or yellow to warn drivers. Tactile pedestrian pads are pressure-activated pads that detect the presence and direction of a pedestrian supplementing the call button when someone stands on the pad. These also apply to bicycles and wheelchairs when they approach a crossing.

These technological devices can be especially helpful for slow pedestrians, in the dark, and at heavy pedestrian flow locations. However, the more elaborate versions are not yet widely available. In the future, the signals could communicate with autonomous vehicles (Elsom, 2018).

Wayfinding Tools

Wayfinding tools provide information to older people with many specifically helping visually impaired pedestrians to find their way. For example, a smart cane is a technology-assisted cane to help visually impaired people navigate and detect obstacles. While a traditional cane cannot detect obstacles at upper-body levels and beyond the cane's length, a smart cane—equipped with sensors and GPS—can function as a sighted guide and help the user travel safely and effectively (Kim & Cho, 2013). Kim and Cho (2013) reviewed 12 existing smart canes that detect obstacles. Among those currently available one version uses ultrasonic waves to detect obstacles on the ground and at knee level in a four-meter range and dangers at the head level within 1.5 meters, using vibrating buttons to inform the user. A smart cane can also help navigation. For instance, another smart cane with a voice assistant helps to find the current location, navigate to new locations, and connect to public transport, controlled from the cane or a smartphone application.

Researchers have also developed devices to help visually impaired people navigate in public transport systems. Using a Wi-Fi-enabled handheld device, the user can listen to the list of stop names along a bus route at a specific bus stop. However, this technology requires fixed base-stations installed at the bus stop (Hakobyan et al., 2013).

Wayfinding tools can help groups beyond those with visual impairments. In addition to helping the visually impaired, these wayfinding tools have the potential to help people with cognitive impairment, navigating to destinations and reminding them of their way home.

Robots for Mobility

A robot is a programmable machine that can automatically execute complex tasks (Moravec, 2021). Many kinds of robots have been used in healthcare settings and homes to assist older people, including social, telepresence, health monitoring, reminder, entertainment, and housework robots, and robots that prevent falls from bed (Shishehgar et al., 2018; Pu et al., 2019).

Some robots can aid mobility both indoors and outdoors. For example, Shishehgar et al. (2018) identified rehabilitation robotic products that can assist with mobility, including walking assistant robots and smart wheelchairs. They found several manipulator service robots with arm-shaped parts to help carry objects. Similar robots were designed to provide physical support with a handle for walking outside, carrying objects, and collecting garbage (Esposito et al., 2016). Mobility robots also include wearable exoskeletons. For example, a light motorized walking-assistant device can help support the body, reduce the load on legs, and propel the wearer forward, which helps older people with restricted mobility to walk and climb stairs with less physical exertion.

While not yet widely accessible, these robots have the potential to assist mobility as well as daily life services near home. In the future, they might also combine with other technologies to provide, for example, wayfinding as well as social functions.

Fall Detectors

Fall detection devices automatically register falls and send messages for emergency help. Lying undetected after a fall may require a long recovery time and cause serious health outcomes (Ward et al., 2012). Outdoor fall detection is often done via individual fall detectors using an accelerometer worn on the wrist, waist, etc. Such individual fall detectors are widely available commercially. To be less intrusive, fall detectors can be integrated into clothing and combine health monitoring functions (Wagner et al., 2012; Ward et al., 2012). To date environmental devices have typically been in the home including video-based monitoring, acoustic frequency, or floor vibration-based methods (Wagner et al., 2012; Ward et al., 2012).

In the future, with ambient monitoring systems, proactive fall detection devices can provide warning and thus prevent falls by analyzing abnormal movement and environmental hazards such as icy walkways (Kang et al., 2010; Ward et al., 2012). These pre-emptive devices are currently not seen in the market.

Motorized Travel

The ability to drive decreases with age and accessing a vehicle also may become physically challenging. Technological devices can help increase older people's mobility and independence, and thus help fulfill personal errands, enable social and public participation, and maintain social connectedness on a larger geographic scale. These devices also include those substituting for human travel and bringing goods home. We also include vehicles that use public streets and airways.

Vehicle Access

Vehicle access technologies refer to devices that enhance older people's access to buses and private vehicles. We identified three types of these devices: aiding access to cars, moving mobility devices into vehicles, and aiding access to buses.

Devices to aid older people getting in and out of a car come in a range from simple handles to complex gadgets ("Awesome Car Gadgets for Seniors in 2020," 2019). In terms of computerized devices, an electronically controlled car seat can move entirely outside the car and move back after the passenger or driver is seated. It also helps an individual to transfer from a wheelchair to a car seat. These products could reduce the large number of fall-related injuries when entering and exiting a car (Dellinger et al., 2008). The second type includes products such as ramps and lifts that help move mobility devices such as scooters and wheelchairs in or with private cars, so an individual can access those devices at the destination. The third type is devices installed on buses that allow wheelchair passengers to easily and independently secure themselves on a bus by placing the wheelchair against the backrest and pressing a lock button.

These vehicle accessories help frail older people and wheelchair users transfer between travel modes more safely and conveniently. In the future, they could be integrated into more public and private vehicles.

Driving Simulators

A driving simulator allows a user to drive in virtual road conditions by operating actual vehicle controls (*Driving Simulator for Rehabilitation, Aging and Human Factors Research*, n.d.). If vision, hearing, and agility decline with age, older drivers may need training and tests with a simulator to maintain safe driving. While not used in the neighborhood environment, it aims to ensure older people can continue to operate vehicles safely in those environments. One type of simulator is a special device combining vehicle controls, sensors, software, and surrounding screens. There are also portable systems including simulator sensors, software, and virtual reality goggles used with the driver's own or the instructor's vehicle, which were designed for older drivers' rehabilitation as well as aging research.

These simulators can both help to diagnose older drivers' skills and provide a safe environment for driving practice. While autonomous vehicles may reduce the need for skilled driving, they are not yet available, so simulators can provide an interim solution.

In-vehicle Devices

Some in-vehicle devices aim to assist older drivers. Though driving abilities are diverse among older people, difficulty with driving at night and in heavy traffic, reading signs, making complex turns at intersections, and responding to traffic signals may increase with age (Mitchell & Suen, 1998).

In-vehicle technological devices can help older drivers to drive more safely and maintain their mobility and independence as long as possible (Eby et al., 2016). Based on 271 academic articles, Eby et al. (2016) reviewed 12 technologies that could potentially benefit older drivers. Some technologies target preventing crashes, including lane departure warnings/mitigation, curve speed warnings, forward collision warnings/mitigation, blind spot warnings, and parking assistance. Some provide information for better driving decisions, including navigation assistance and intelligent speed adaptation. Others include adaptive cruise control, automatic crash notification, night vision enhancement, adaptive headlights, and voice activated controls. Eby et al. (2016) found most were useful though some had false alarms or other problems.

Some of these technologies have been seen in specific products in the market. For those who maintain driving, in-vehicle technologies could make driving easier and safer, though acceptance may differ between individuals. This is an area where there is a great deal of current research and development.

Autonomous Vehicles

An autonomous vehicle (AV), or a self-driving vehicle, refers to the highest level fully automated vehicle (Millonig, 2019). Though AVs could potentially increase car dependence, they are expected to improve older people's mobility, increase traffic safety, eliminate driving stress, and promote social connectedness (Sohrabi et al., 2020; Zandieh & Acheampong, 2021). Numerous AV products have been developed and applied, though not completely implemented.

Automated public transport is likely to be the most accessible AV, particularly for older people with lower incomes (Millonig, 2019). An autonomous shuttle bus or shared vehicle can carry a few or a dozen passengers on a route, which can apply to multiple scenarios such as ride-hailing trips for residents of retirement communities and fixed-schedule last-mile travel to transport hubs. However, acceptance could be an issue due to not trusting and not recognizing the advantages, though some studies found that older people are interested in using AVs to deal with mobility barriers (Faber & van Lierop, 2020).

Both autonomous cars and buses promise to meet diverse mobility demands of older people though fully autonomous vehicles have been slow to market. As most are being developed for the general population, the key will be to provide features needed by older people such as easy access to vehicles for those with mobility aids such as walkers.

Figure 2 Autonomous shuttle bus example 1
https://commons.wikimedia.org/wiki/File:NUSmart_Shuttle_EasyMile_EZ10_RD3173E.jpg

Figure 3 Autonomous shuttle bus example 2
https://commons.wikimedia.org/wiki/File:Easymile_autonomous_bus_-_Bad_Birnbach_2.jpg

Delivery Vehicles

Delivery vehicles include robots, autonomous vehicles, and drones. They deliver medications, meals, groceries, and other packages to a customer's home replacing mobility of the older person. Though these technologies were not developed particularly for older people, they can be especially helpful for them.

Autonomous robots have been developed to deliver goods and packages locally. These robots usually go on wheels on sidewalks at slow speeds and can handle traffic, obstacles, and terrain. They often deliver a few packages per trip within several miles.

In contrast, on-road autonomous vehicles with high capacity can handle diverse errands and serve a larger geographic scale. An autonomous vehicle can even bring a mini-mart to consumers' locations for them to shop for fresh food. However, it is challenging for autonomous vehicles to unload goods beyond the road. Interestingly, a two-legged robot can team up with an autonomous vehicle and bring the package from the car to the door.

For time-sensitive and emergency deliveries, drones (automated aerial vehicles) may be a fast and safe method to deliver lightweight packages such as medicines and medical supplies to older people's homes (*Drone Delivery*, 2020). Drones also have been designed to deliver goods for everyday life.

Delivery technological devices could provide more innovative services using autonomous vehicles and drones. In the future, they could be further developed to deliver beyond the curb or yard.

Figure 4 An example of food delivery robot
https://www.flickr.com/photos/paulwasneski/33192402562

General Outdoor Activities

Technological devices also support and encourage older people's other outdoor activities by monitoring personal health and air quality, making public events more enjoyable with an enhanced hearing experience, providing responsive streetlights and street furniture to meet special needs of older pedestrians, and monitoring public and personal physical activities. This is the least developed area but one with much potential.

Air Quality Measurement Tools

Air quality measurement tools provide real-time air quality information. While many tools detect indoor air quality, some air quality monitors are designed for both indoor and outdoor use and are portable. Outdoor activities can benefit older people's health. However, even short-term exposure to air pollution threatens health, especially for people with respiratory diseases, which older people especially suffer from (Whittemore, 1981; Xie et al., 2020). A portable air quality monitor informs older people to reduce activities in unhealthy environment if the air quality of a destination is low. It could be particularly useful for older people who are sensible to pollutants and those living in regions with more air pollution.

In the future, such monitoring could be integrated in wearable technologies that monitor both personal health and ambient temperature and air quality. It might be possible to add such monitoring to other devices such as vehicles and furniture.

Outdoor Audio Enhancement

Outdoor audio enhancement devices refer to assistive listening devices to enhance the listening experience in outdoor activities and events, such as induction hearing loops and alternatives, especially for people with reduced hearing. Different from normal hearing aids which are helpful in quiet one-on-one situations, outdoor audio enhancement devices can improve hearing clarity in noisy public spaces (Keller, 2017). About half of older people have mild to severe hearing loss based on studies in the US (Lin et al., 2011; Dalton et al., 2003). Hearing loss is associated with communication difficulty and can decrease social engagement (Dalton et al., 2003).

Based on electromagnetic induction, an induction hearing loop, or a hearing loop, is a system installed around a venue to assist people with T-Coil enabled hearing aids (a major type of hearing device) to hear an event more clearly. Hearing loops have been widely used in indoor and outdoor spaces such as schools, churches, airports, and stadiums. Though the system does not need additional receivers, it requires that the user wear hearing aids and that the locale has an induction loop installed.

Only a minority of older adults with moderate hearing loss use hearing aids, so alternative technologies are helpful (Lin et al., 2011). A wireless headphone for seniors can directly connect to any audio source via a transmitter that connects to a physical audio output. Such devices can be used in diverse scenarios such as community activities and bus tours for sightseeing. Products can also include a microphone that helps two-way communication in an event.

These outdoor audio enhancement devices can improve the listening experience, make public spaces such as stadiums and airports more inclusive, and encourage social engagement of those with hearing loss. Future diverse types of devices for those with and without hearing aids would help older people participate in public events.

Smart Streetlights

A smart street lighting system communicates with clusters of streetlights, transmits data to a secure server, and manages all the lighting devices in a web-browser interface (Bruno et al., 2012). An individual lamppost in the system often uses renewable energy and has sensors, cameras, controllers, and communication components, which enable it to respond to the environment (e. g., luminance and motion) and monitor air pollution, traffic, parking, and community security. It also enables emergency response by 911 operator-controlled location identification. Security monitoring by cameras or gesture recognition sensors also allows management staff to proactively report safety issues (Bruno et al., 2012).

Lights with motion sensors can be beneficial for older people with reduced eyesight. Falling is among the biggest risks for older people (CDC, 2020). In residential areas, streetlights are often dimmed to avoid interfering with residents' sleep. Streetlights with motion sensors can provide bright lighting when people are passing by and remain dimmed the rest of the time ("GSMA Smart Cities Guide," 2017).

Lights with motion sensors have been used widely in both indoor and outdoor public areas. In the future, we imagine the smart streetlight system could benefit older people as it can function as an accessible emergency response system, allowing people in need to call for help using a button on the lamp post, and proactively identifying safety issues as well.

Smart Street Furniture

Smart street furniture provides public services and information, is often self-powered and interactive, and enables data collection such as usage of the furniture (Mueller, 2017). Smart street furniture can respond to people with different needs. For example, older people who are frail or have difficulty in standing from sitting may desire adaptable furniture in outdoor spaces (Chen et al., 2021). A prototype in Britain detects people with a special tag and pre-registered choices when they approach and provides them with brighter streetlights, extra seats, or a longer green light to cross the street. Other types include smart public toilets and benches. Smart public toilets can sense improper use and automatically clean the toilet and floor. Additionally, a smart park bench currently under research serves older people by detecting a user and adjusting its tilt to help them sit down or stand up.

Smart street furniture could increase older people's use of public space and social connectedness by providing accessible information, convenient facilities, and other specific functions to meet personalized needs. Such furniture has not yet been widely deployed, however. In addition, more interactive street furniture is needed where it inspires older people's engagement and thus increases social interaction.

Smart Bus Stops

Equipped with diverse technologies, smart bus stops help people use transportation services more effectively and make waiting at bus stops more comfortable. Smart bus stops combine multiple functions such as information, ticket vending, free WiFi, phone charging, air conditioning, and ordering taxis. Many provide real time bus information such as bus arrival and departure time, traffic conditions, and passenger capacity, based on bus tracking and a web-based system (Kadam et al., 2018; Ram et al., 2016). Smart bus stops are often solar powered and use interactive displays which present information in both visual and audio format.

A few features make smart bus stops especially beneficial for older people such as real-time information, taxi-ordering, and air purifying and conditioning. Real-time information such as occupancy of the buses and availability of a wheelchair space could can be particularly helpful for older people to plan their trips (Padrón Nápoles et al., 2020). A taxi-ordering function allows people to order a taxi or online car-hailing service (e. g., Uber) without a smartphone. With similar intentions, one-button-call-taxi devices were installed on multiple locations in Shanghai in 2020. However, this service has not been well supported by taxi drivers due to low trust in the calls. In addition, using air purifiers and heating and cooling devices, enclosed smart bus stops make waiting at the stops more comfortable and healthier in extreme weather. Such features have been implemented in cities with cold winters and hot summers such as Seoul, South Korea.

Though smart bus stops can benefit older people, some features such as real-time information of occupancy and wheelchair space have not been widely implemented. Additionally, taxi ordering from a bus stop is not yet well supported in the market. Innovations in service management are needed. When combining voice control, an audible menu, and communicating with personal devices such as smart canes, the smart bus stops could be more helpful for those with visual impairments.

Public Space Physical Activity Monitors

Public space physical activity monitors count people's physical activity at an outdoor location, aiming to encourage physical activity such as excise and active transport. One such technology designed for older people is the outdoor gym. Originating from China, senior playgrounds equipped with exercise machines for older people have been adopted in many cities such as London, Berlin, and Toronto (Traverso, n.d.). Outdoor gym devices are an upgrade where the exercise machines are designed to be more engaging and rewarding. For example, a bike or a wheelchair accessible hand bike can generate electricity to charge devices while exercising the body. An energy display unit can store human energy and display the number. These devices can also be used for community workout activities. Another type of physical activity monitor is the people counter. This device counts and displays the number of people who walked (or cycled) over a path. This can give positive feedback to older pedestrians and motivate older people to walk more.

These technological devices can enhance physical health of older people and provide opportunities of social encounters and group activities. In the future their potential to foster social interaction could be developed.

Personal Physical Activity and Health Monitors

Many devices such as wristbands have been produced to monitor and diagnose the user's health status and physical activities, which could be useful for older people. Some devices are designed to serve older people, such as a necklace that can provide GPS tracking and summon emergency help wherever one goes, and a watch that provides access to emergency help and monitors physical activity and heart rate. Some also combine fall detection. These devices encourage outdoor activities with less concern about accidents.

Wearable physical activity monitors are a major consumer product line. The challenge in the future will be to develop versions relevant to older people, particularly those with mobility limitations and cognitive problems.

Discussion

Technological Domains and Functions

This paper set out to answer a key question: what new urban-scale technological devices are available to support older people using their neighborhood and city environments as they age in place? In this discussion we draw out key findings and speculate where there is potential for more development.

Many current technological devices focus on mobility, with multiple examples for each type of mobility-related technology. Mobility is the basis of independently using many outdoor spaces. Technological devices can improve mobility in multiple ways—for pedestrians, in vehicles, in terms of physical mobility, for wayfinding, and even deliveries.

In addition, safety is well-represented. Many of the devices we have classified as related to mobility have a dual function of safety—to help people cross streets, find their way, or drive without accidents. This is again logical, as physical safety is a key dimension of mobility and independence for older people.

Mobility and safety are not the only life domains the identified devices serve, however, and existing and near-term technological devices cover a wider range of domains and functions including everyday activities and leisure, physical and mental health, and social connectedness (see Table 2). Arguably, many of the mobility devices help with everyday activities like shopping and leisure, and devices as varied as delivery drones, audio-enhancement, and public gyms support such endeavors.

Less supported are physical and mental health and social connectedness, though this could be due to other kinds of technologies being more relevant, such as telemedicine or social media. Results show that, in the physical and mental health domain, technological devices can help older people by monitoring public and personal physical activities, detecting falls, and monitoring air quality to avoid activities in polluted air. Arguably, delivering medical supplies using drones is also a health-related technology. Products are generally widely available except for delivery devices.

Social connectedness has been only somewhat supported by the urban-scale technological devices. Outdoor audio enhancement improves the experience of community activities and public events. Smart street furniture and public space physical activity monitors also encourage outdoor activities and increase social encounters. Social health is one of the pillars of health and wellbeing (*Constitution*, n.d.). Considering the large number of older people suffering from loneliness, more urban scale technological devices should be developed to support social connectedness of older people (Lyu & Forsyth, 2022). The COVID-19 pandemic may provide some impetus for such development.

Complex Landscape of Devices

While technological devices focus on several different life domains, it is necessary to understand these devices in a complex and dynamic landscape. This involves dimensions related to technologies, time, and the diversity of older people and of places.

The first issue is the large number of devices that make up the gerontechnology landscape. Obviously from the inventory, many different technological devices are available or being developed. The variety of specific devices can be overwhelming, though in this paper we identified the types of technologies rather than every device. Additionally, this inventory did not include software, or devices primarily used in the home or healthcare setting, and therefore the technology landscape is even more complex.

Not all technologies are at the same level of development, however. Though a readiness evaluation and cost are not the focus of this review, many ideas have not been brought to scale, so they are not widely available. Even in areas with devices already on the market, they did not always function at a level needed for wide usage, while the others are still in the development and trial stage.

Meanwhile, older people are diverse and their needs are likely to change over time, necessitating using different devices or using devices in new ways. As such, it is important to see the device landscape more comprehensively, and to focus on how technologies can be used as a suite. This does not necessarily mean they all need to be connected to each other, but that they can complement one another and service dynamic needs. Some of the technologies in the inventory such smart crossing signals, smart bus stops, and smart street furniture begin to do this, responding to different needs.

Similarly, it would be necessary for city managers, planners, and designers to consider how to bring together diverse types of devices in a systematic approach to age-friendliness in the city. This approach could start from examining different scenarios, for helping older pedestrians, older drivers and passengers, or older participants in outdoor events (refer to Table 2). For each scenario, a suite of technological solutions may be used to accommodate diverse needs such as lower mobility, visual impairment, hearing loss, and cognitive impairment. Physical scale should also be considered in the approach because some devices support older people in the whole city (e.g., vehicle access) while others may only apply in the neighborhoods (e.g., smart crossing signals, delivery robots).

Another issue is comprehensive usability of the devices. These include devices that work for those with cognitive as well as physical challenges, connections between devices and other technologies such as telehealth or social media, devices that can help older people function in a wide variety of urban environments, and methods for accessing devices such as systems for sharing or making them cost effective.

Finally, urban places vary, and specific technologies will only be relevant and cost effective in specific locations. Some may be ubiquitous, such as delivery robots. Others may be useful beyond an aging population but still be relevant in only intensively used areas (e. g. smart crossings). There is not a one size fit all approach, which is an issue we expand on below.

Gaps and Potentials of Urban Scale Technological Devices for Aging

Gaps do not always imply potentials, and potentials can exist beyond the gaps. It may be tempting to look at gaps in Table 1 and Table 2 and conclude that those are the areas where more technological development needs to occur, but this is not necessarily the case. For example, in terms of technology functions, devices typically help with monitoring and intervention. Fewer deal with diagnosis which is an emphasis of technologies at the individual and household level. However, diagnosis and screening in public areas raise privacy concerns and this may not be the best location for such activities. Looking at life domains, mental and physical health may be indirectly helped by many of the devices related to mobility and safety, even if a narrow version of health is not the primary focus of those technologies. Still, there are some areas where technological devices could better help older people thrive in outdoor urban spaces and we turn to those issues next.

Facilitating Social Connectedness

Social connectedness could be better supported by technological devices in an urban context. Though social media and other virtual technologies can expand social interaction, in-person meetings and encounters in the local communities are still valuable for older people's social health and overall wellbeing (Alidoust et al., 2019). Some devices increase public participation and social connectedness; however, their diversity is very limited and some of them are not yet available. However, in the future various kinds of smart street furniture, as well as smart bus stops and public physical activity monitors, could offer more functions that attract small group activities and encourage social interactions. In addition, devices for individual outdoor use, for example, smart canes, can also combine social functions such as chatting, like a robot companion, or real-time connection to family members (Shishehgar et al., 2018).

Targeting the Diversity of Older People

Many devices developed for the general population could better serve older people by targeting their needs. For example, various autonomous vehicles (AVs) could help older people, but these AVs need to be age-friendly, being easy to enter and exit, as an example. Smart bus stops need functions such as ticket vending and interactive information that are accessible for wheelchair users and visually impaired people.

Some devices will likely be used only in key locations where they are of most use; however, the implication is to make sure that needs of older people are factored into assessments about which locations receive treatment as well as the kinds of features. For example, embedded smart crossing signals are of use beyond the aging population but may be too expensive to install in less intensively used places. Similar examples include outdoor audio enhancement devices such as induction hearing loops. Urban spaces with these age-friendly devices contribute to more equal and inclusive environments.

Further, to make full use of the devices, there need be age-friendly services to connect older people with these devices. Considering technological knowledge gaps in older people it is essential to ensure easy and effective ways for older people to reach devices when they need. For example, as Millonig (2019) pointed out for AVs, older people cannot benefit from the technology if they are not able to plan, book, and pay for the service in ways they are familiar and competent with.

Similarly, for older people with lower incomes, creative business models (e. g. buying, renting, or sharing), subsidies, and public recycling programs are needed to support their access to technological devices which can be expensive. This has implications for health equity. Cost has been frequently identified in the literature as a barrier to the adoption of aging technology among older people (Peek et al., 2014; Yusif et al., 2016). Besides innovative business models for individual devices, policy makers, urban planners, and designers could improve access to public devices such as pedestrian crossing sensors, autonomous shuttle buses, and outdoor gyms, which may reduce dependence on individual devices.

As technologies or needs change, governments and individuals will need to decide if and how to upgrade the technology with implications for tradeoffs between investing in such technologies and other pressing priorities. Individual or private-market technologies (e.g., smart canes, delivery robots) also rely on government supplied infrastructure, such as sidewalks, being at a certain level of provision and repair. Policy makers and planners will face difficult decisions, particularly in locations with few resources.

Few urban scale technological devices target cognitively impaired people. Such devices instead focus on the home and health care environments. Still, many people with cognitive impairments live in community settings and urban scale technological devices could help such people to move around more safely. There are some positive examples, however, such as smart crossing signals that are triggered even if one forgets to push the call button. Wayfinding devices, such as smart clothing with navigation function, could help navigate. This is a matter of fairness.

Finally, older people live in a variety of environments which may require different kinds of technologies. However, there may well be environments that miss out, particularly for the more expensive devices. For example, robotic wheelchairs allow people with both functional and cognitive decline to get around more easily. However, the infrastructure of streets and sidewalks needs to support these devices. Disconnected sidewalks or narrow pathways with many obstacles can make it hard to use these wheelchairs. While this paper focuses on urban environments, including villages, many older people live in rural areas which raises additional issues.

Conclusion

As people age, declining function may prevent older people from going outdoors, especially in complex urban environments. While smart city technologies facilitate the efficiency and convenience of urban life for many people, older adults could be left out due to different needs. In this review, we targeted older people and explored what new urban-scale technological devices are available to help older people to live independently and comfortably in their neighborhoods and cities. We identified the range of urban scale technological devices to help older people in outdoor spaces and how they help with life domains. The results show that available and emerging devices focus on improving the mobility and safety of older people and population with special needs. Meanwhile, some attention has been paid to everyday activities and physical and mental health. With such support, older people with diverse needs could have more confidence to participate in outdoor activities independently. To better service older people with urban scale technological devices, a few aspects could be strengthened: facilitating social connectedness, better targeting the special needs older people, adapting the built environment to embrace new technological devices, and connecting devices.

This paper informs practitioners, policy makers, and caregivers about the cutting-edge practice that can help older people to live safely, effectively, and enjoyably. Practitioners such as urban planners, designers, and transportation planners could consider using some of these emerging technological devices in the urban system, coordinating technology of diverse types to achieve a comprehensive approach to benefit older people. Understanding the relevant urban scale for technologies can also help city managers and policy makers understand technological options for enhancing age-friendliness in urban spaces. Finally, this paper provides a reference for aging technology engineers about the gaps and needs to serve all life domains of older people.

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[i] Carroll (2017, p. 18) defined technology as "(a) something that is always inherently intelligent enough either to function, to be used to function, to be imbued with, or to be interpreted as having, a function that only intelligent beings (human or otherwise) have the ability to comprehend; (b) something devised, designed (i.e., primary intention), or discovered (i.e., secondary intention) that serves a particular purpose from a purely secular standpoint, without requiring that mankind be responsible for it, though he may be (i.e., the aspect of reflexivity through purpose in that salt doesn't inherently "elevate" or do anything deliberately, but it does "elevate" the boiling point of water, which it has been found to do and can be considered to serve a purpose); (c) a significant beneficiary of rationally-derived knowledge that is "used for" a purpose, without itself necessarily being translated into something physical or material that "does" (e.g., instructional methodologies in education, processes, ideas)."