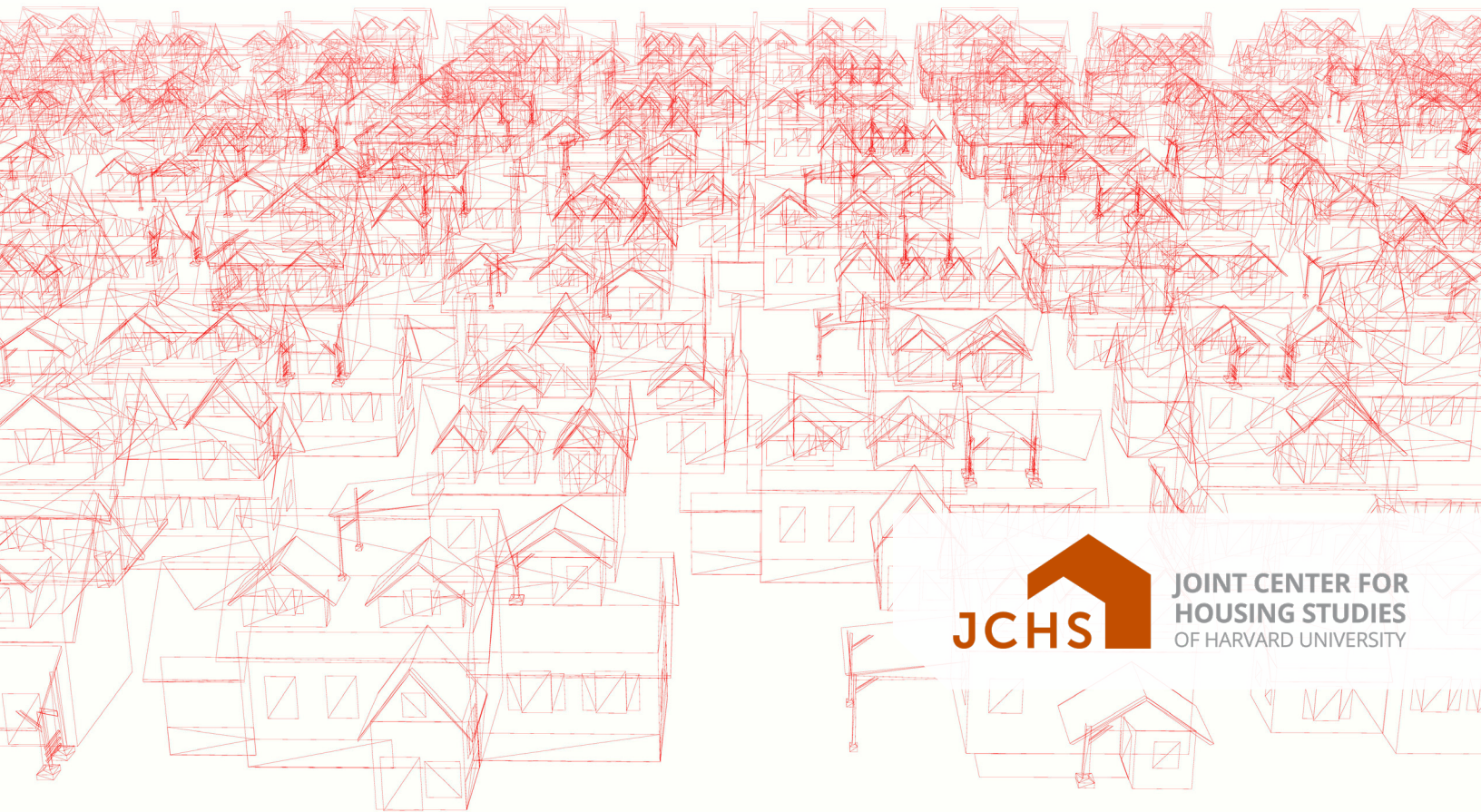# Centering the Home in Conversations about Digital Technology to Support Older Adults Aging in Place

MAY 2023 | JENNIFER MOLINSKY, SAMARA SCHECKLER, BAILEY HU

JCHS **JOINT CENTER FOR HOUSING STUDIES** OF HARVARD UNIVERSITY

Joint Center for Housing Studies
Harvard University

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Introduction

As digital technology transforms housing markets, production, finance, and energy efficiency, it also has the potential to reshape the residential experience. Domestic technologies have evolved for generations, and advances in appliances, communications, entertainment, and safety systems have increased convenience, safety, and enjoyment of the home. Today's smart home technology continues to transform how we use our homes.

For the growing population of the nation's older adults, digital technologies also have the potential to change the role that the home plays in supporting activities of daily living as well as health maintenance, management, and care, with the potential to enable older adults to remain in their own homes longer as their functional capabilities evolve. These technologies are sometimes described as "ambient assisted living," which Blackman et al. define as "the use of information and communication technologies (ICT), stand-alone assistive devices, and smart home technologies in a person's daily living and working environment to enable individuals to stay active longer, remain socially connected, and live independently into old age" (Blackman et al., 2016). We focus in this paper on the subset of ambient assisted living technologies that monitor and provide feedback on health.

Many of these technologies are not new, but they are increasingly enabling the communication of health information with caregivers and healthcare providers. Yet while these technologies have the potential to enhance health and independence for those residing in the community, they also raise critical questions about how effective these technologies can be when implemented in housing that is physically inadequate, does not meet accessibility needs, or is unaffordable—conditions that already affect millions of older adults, particularly people of color, those with low incomes, and renters. A second set of questions revolves around how digital technology for supporting health might change the ways that older people experience and perceive their homes.

These questions became more relevant during the Covid-19 pandemic, when the federal government loosened regulations around telehealth (Tinetti, 2022) and allocated more funding toward in-home care (Centers for Medicare and Medicaid Services, 2021b). In June 2021, 16 percent of adults 65 and above said they were more likely to receive home health services

compared to before the pandemic (Bestsennyy et al., 2022). However, aside from some acknowledgement of disparities in internet access and digital literacy (Ng et al., 2022), analyses of these changes have not tended to consider older adults' wide range of home settings and financial situations, or the capacities of their homes to support technology, which can lead to inequities in adoption and effectiveness across the older population.

We consider the unequal deployment of in-home health technologies to be a moral problem; as Chung, Demiris, and Thompson argue, "equity of access " is essential for an ethical approach toward smart home devices (Chung et al., 2016). For digital technology to meet its promise to support older adults at home—including those with limited incomes and unstable housing—housing challenges must be more carefully considered in the healthcare realm. In addition, greater collaboration across the housing and healthcare fields in the development and deployment of digital technology used in home settings can ensure that it truly enhances older adults' wellbeing.

The Promise of Digital Technology to Support an Aging Population

Increased longevity and the aging of the baby boom generation are contributing to unprecedented growth in the older population (Rowe et al., 2016). By 2030, fully 20 percent of the nation's population will be 65 or over (Vespa et al., 2020). The leading edge of the baby boomers will reach age 80 in 2025, and thereafter the population of those 80 and over will soar. Indeed, the number of people 85 and over is expected to nearly double by 2035 (Vespa et al., 2020).

Most of these older adults will live in the community and not in group quarters like nursing homes. The vast majority will head their own households, and the Center projects that the number of households headed by someone age 80 or over will double within the next twenty years to reach 12 percent of all US households (JCHS, 2019).

At older ages, people are more likely to have chronic health conditions and experience challenges with mobility, cognition, self-care, household activities, hearing, and seeing. These increase healthcare utilization as well as the need for long-term services and supports (LTSS), including help with activities of daily living (ADLs) (e.g., bathing, dressing, and eating) and

instrumental activities of daily living (IADLs) (e.g., food preparation, housekeeping, and financial management). A 2019 study estimated that 70 percent of people who reach age 65 will have severe LTSS needs at some point, defined as having two or more ADL difficulties or severe cognitive impairment, and needing either paid or unpaid assistance (Johnson, 2019). Recent research also suggests that having lower lifetime earnings puts one at higher risk for serious LTSS needs lasting for five or more years (Johnson et al., 2021).

Despite increases in chronic conditions and functional limitations that occur with age, most older adults prefer to remain in their own homes and communities for as long as possible (AARP Research, 2018; Barrett, 2015; Keenan, 2010), which we define here as a desire to "age in place."[1] A good deal of research has explored motivations to age in place, pointing to feelings of comfort, familiarity, a sense of "rootedness" and control, and memories of family and traditions (Mackenzie et al., 2015; Molinsky et al., 2019; Oswald et al., 2007; Oswald & Wahl, 2005; Pynoos et al., 2008). Homes also tie people to communities and the familiar networks and supports within them. Another driver of aging in place may be negative perceptions of alternative settings like nursing homes (Forsyth & Molinsky, 2021). Indeed, over the last several decades, older adults have been increasingly likely to live in the community rather than in nursing homes or other institutions as options for supportive services delivered to private homes have increased (Pynoos et al., 2008).

Remaining in one's home (or moving to another within the community) is not without a host of potential challenges for those with chronic conditions and functional limitations, including difficulties accessing medical care and needed services; coping with housing-related issues such as a lack of accessibility, safety, and affordability; managing new costs associated with supports and services; and remaining engaged with others. Digital technologies, however, offer the potential to support aging in place by addressing some of these challenges, including facilitating access to care, supporting health and wellness, providing help in the event of an emergency, and even providing a more comfortable setting for the delivery of acute medical care.

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[1] As we use the term here, aging in place refers to preferences to remain in the community and not institutional care. Aging in place can occur in a longtime residence of one's own, another home, or the home of a family member.

Our focus in this paper is on Ambient Assisted Living (AAL) designed to support health. Broadly, AAL refers to technologies that can enhance autonomy, social connection, safety, and wellness for older adults, enabling them to remain in a preferred environment (Blackman et al., 2016; Grossi et al., 2020).[2] In the health sphere, AAL includes devices that help monitor and manage chronic conditions, such as wearable technology that collects data on physical activity, blood sugar, or heart rate and rhythm. It includes emergency detection and response technology, such as fall detection apps in smartwatches, as well as systems that remotely monitor behavior, such as devices that alert family if someone has not opened their refrigerator in a specified time frame, or medication dispensers that alert caregivers of atypical use. All of these may be used to craft treatment or wellness plans, identify emergent situations, or remind users to take medication or other actions (K. Kim et al., 2017). In our usage, AAL includes telehealth technology, including apps and software facilitating virtual visits with care providers.

Although forms of AAL have existed for decades, recent technology is often smaller, wearable, and easier to use (Philip et al., 2021). Newer devices and software are also increasingly able to share information about older adults' health with caregivers and healthcare providers. A critical feature is the capacity of technology to collect data in the home that is shared and analyzed outside the home. Because of this, most of this technology requires internet access.[3]

AAL technologies range in complexity and technical requirements, and some may perform more than one function. Table 1 presents a few examples of specific technologies that show the breadth of devices and software considered AAL.

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[2] Because "ambient assisted living" is often embedded in the home environment, we sometimes use "smart home" interchangeably. Both terms represent systems that include sensors and smart devices, although "smart homes" offer a wider variety of services that extend beyond health and monitoring (Marikyan et al., 2019). We also use telehealth and telemedicine interchangeably, though they are distinguished by some as relating to remote diagnosis, monitoring, and treatment (telemedicine) and technologies to help patients manage illness and improve self-care (telehealth) (Kvedar et al., 2014).

[3] There is an abundance of existing and emerging technology to support health. Some technology provides the option for in-home use only or for connection outside the home (e.g., a monitor alerts someone if their blood sugar is low but can also be programmed to send alerts to family or data to a medical provider); for our purposes we focus on the aspects of that technology that involve interaction with someone outside the home.

Table 1: Digital Technologies Supporting Aging in Place

Device name	Functions	Listed requirements	Price range
Age in Place Kit	Set of in-home devices, including movement sensors, emergency buttons, and drawer or door sensors, paired with mobile software that monitors daily activities and sends alerts to caregivers.	Internet, smartphone, batteries	$600 plus optional add-ons from $49-294
Amazon Astro	Mobile robot can perform remote checks in different parts of house (on same floor), send reminders about medication or other tasks, alert caregivers about activity, and enable hands-free calls for help.	Internet, subscription to Alexa Together	$1000 plus $20/month
Hero	Smart pill dispenser paired with remote caregiver monitoring and medication management app. Caregivers can receive alerts and set restrictions.	Internet, smartphone	$100 plus $30/month
HipaaBridge	HIPAA-compliant text, voice message, and video call platform for doctors, nurses, emergency responders to communicate with each other and patients.	Internet, smart devices (computers, tablets, phones)	Unknown
Livpact	Platform allowing caregivers, doctors, and pharmacists to track daily activities, share health records, and modify care plans. An "AI care companion" helps organize care plans and communications.	Internet, smart devices (computers, tablets, phones)	Unknown
Reemo	Smart LTE watch tracks and shares health and fitness data, allows for phone calls and texts, and sends reminders. Can be programmed for specific conditions such as cardiovascular disease.	Cellular network coverage	Unknown
VitalPatch RTM	Wearable patch monitors vital signs and arrhythmias and provides continuous analysis. Software platform allows clinicians to view data and receive emergency alerts.	Internet, smart devices (computers, tablets, phones)	Unknown

There is little public data on how many of these technologies are currently in use by older adults, or the extent to which they are integrated into everyday life (e.g., one may own a smart watch with fall detection capabilities but not actually wear it).[4] During the COVID-19 pandemic, telehealth use expanded, facilitated in part by easing of regulations; older adults were among the beneficiaries (Goldberg et al., 2021), though usage was more common among those with technical literacy, broadband access, and those without cognitive or sensory difficulties (Goldberg et al., 2021; Kruse et al., 2020; Ng et al., 2022).

A special application of digital technology to healthcare delivery is through "hospital-at-home" programs, in which acute-level care is delivered in private homes rather than in a hospital. While hospital-at-home programs have existed in the US and internationally for years (CMAJ, 2023; Duke & Street, 2003; Federman et al., 2018), the urgent challenges facing hospitals during the COVID-19 pandemic led the US Centers for Medicare and Medicaid Services (CMS) to expand coverage for such programs under the Acute Hospital Care at Home (AHCaH) program, aimed at patients who had been admitted as inpatients or seen in an emergency department and who had particular acute care needs.[5] As of January 2023, CMS had approved 260 hospitals in 37 states for AHCaH (CMS, 2023). Under AHCaH (and similar hospital-at-home programs developed earlier), hospitals provide comparable services and equipment to people at home as they provide to inpatients, including durable medical equipment, respiratory support, infusions and pharmaceuticals, and various therapies, social work, and care coordination (Clarke et al., 2021). Daily in-person visits by registered nurses and/or mobile EMT teams are required and supplemented with virtual visits. Patients' vital signs may be monitored remotely, for instance through the wearable patch listed in Table 1.[6]

Digital health-related technology offers a number of potential benefits to older people seeking to age in place, including increased independence and wellbeing, comfort and control

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[4] AARP surveys show that ownership of smart home devices among 50-plus older adults rose from 10 percent in 2019 to 19 percent in 2020 (AARP Research, 2021). In addition, 25% of those who owned this technology in 2020 were confident using it. However, these figures are not broken down by device type.

[5] A trial program at Brigham and Women's Hospital and Brigham and Women's Faulkner Hospital in Boston served patients with infections, heart failure, chronic obstructive pulmonary disease, asthma, and some other conditions (Levine et al., 2020).

[6] An example of an acute-care-at-home program is that of New York City's Mount Sinai Hospital, which operates under its geriatrics department (Mount Sinai, n.d.).

over their environments, convenience, and—though data are limited—potentially better health outcomes.

Increased Independence and Preferences for Care at Home

Digital technology can help fill gaps that develop between a person's functional capacities and their environments in later life (Mahmood et al., 2008). A home that is well aligned with a resident's needs can increase independence, while a mismatch between a resident's needs and home design can increase reliance on others for support (Georlee et al., 2020; Gitlin, 2001; Stark et al., 2017; Wahl et al., 2009). Technology can reduce the need for assistance from other people; for example, smart home technology might assess daily fluctuations in cognitive capacity for someone with cognitive decline, identifying times of day someone typically functions at their peak (Choi et al., 2019). Technology could help the resident locate objects and offer recognition aids, medication reminders, and task completion supports (Demiris & Hensel, 2008).

Monitoring technology can also support independence by providing a way to signal caregivers or emergency responders in the event of an emergency such as a fall or cardiac event. This may be particularly helpful for older adults who live alone and are physically isolated from others, giving older people and their families peace of mind that help will be delivered quickly if needed. This sense of security may help forestall a move in with family or to assisted living.

The portability of newer technologies (e.g., wearable patches, smartwatches) can extend these benefits beyond the home into the community, expanding the boundaries of older adults' environments while also reducing isolation. With technology increasingly integrated into multi-use smart devices, monitoring becomes increasingly convenient and less obtrusive, and also associated with less stigma (Blackman et al., 2016; Ward et al., 2012).

Finally, digital technologies can give older users greater control over who is privy to and involved in care and chronic condition management. For example, though data from wireless cardiac monitors is shared outside the home, these devices may preserve privacy better than employing an in-person care giver or moving to a setting that offers onsite healthcare. Similarly,

blood glucose monitors can be set to alert specific family members of emergent issues—but at the discretion of the user. Well-designed technology could empower older adults to take greater control over the types of information they share and the scope of their care network. These technologies can reduce reliance on professionals such as home health aides for monitoring tasks related to chronic care management, increasing an older adult's independence. Digital technologies also support independence by helping people stay healthier so that they do not need additional supports and services. Apps that monitor conditions or track fitness, sleep, or nutrition can increase wellbeing, and that in turn can support preferences to live in the community.

Hospital-at-home programs may also support older people wishing to receive care in their homes even in the event of certain acute medical problems that would otherwise warrant an inpatient stay. A study published in JAMA Internal Medicine in 2000 found that, with expectations of similar health outcomes, about half of patients preferred home care (Fried et al., 2000). Technology has evolved a good deal since then, with more opportunities for remote monitoring and video check-ins, making it possible that higher shares might report this preference today.

Increased Convenience and Lower Costs

One of the oft-touted benefits of technology is convenience. Travel to a healthcare site can be time-consuming, expensive, and difficult to arrange (particularly for non-drivers or those without someone to drive them), and telehealth systems that facilitate virtual visits and monitors that reduce the need for in-person testing can reduce these barriers. These gains may be particularly beneficial for those in low-density settings with few transportation options besides private cars and limited access to providers, especially specialists (Rural Health Information Hub, n.d.).

Digital monitoring can also increase efficiency and lower the cost of supports and services, particularly helping lower and middle-income older adults who do not receive support through Medicaid Home and Community-Based Services. Older adults who struggle with instrumental activities of daily living like financial management may find technology

interventions a reasonable substitute for paid staff or family help. For instance, banking software that tracks spending and alerts an older adult when bills are due or automates payments can adequately simplify these essential tasks.

Though it is not the focus of this paper, digital technology can also result in cost savings to providers and insurers, a significant impetus for its development and adoption (Bestsennyy et al., 2022). The increasing share of older adults in the US is likely to heighten the prevalence of chronic health conditions and associated healthcare costs. Technology focused on prevention and early detection of health changes can result in better clinical outcomes and less expense to the healthcare system. Acute care at home could reduce costs to hospitals—though as we note below, some of those costs may be shifted to unpaid caregivers and older adults themselves.

Studies of Health Outcomes

Does digital technology in the home help older adults achieve desired outcomes of greater independence, more convenience, and better health outcomes? Given the breadth of technology, its continued evolution, and changes in older adults' acceptance of it, it is difficult to speak to effectiveness at a high level. However, literature reviews of peer-reviewed studies report some positive results. One review of 48 studies conducted between 2010 and 2014 found that technology used for monitoring cognitive decline and mental health reduced symptoms of depression and emergency department visits, and that technologies that monitored health conditions resulted in improved blood pressure control. The authors found no evidence for success in disability prediction, fall prevention, or health-related improvements in quality of life (Liu et al., 2016). Another review published in 2018 of 31 studies of home health technology, including long-distance communication technology and home monitors, found overall positive results for self-management of chronic conditions (Guo & Albright, 2018). A 2023 review of 23 studies of the effectiveness of home health monitoring technology found older adult users had improved outcomes in conditions including heart failure, chronic obstructive pulmonary disease, and diabetes, as well as increased physical activity; however, the effectiveness of long-term, general monitoring was limited (Chan et al., 2022). These studies touched on disparities in access to technology, willingness of older adults to adopt

technology, and concerns over privacy and control. None discussed the physical home as a setting for technology use.

Regarding hospital at home in particular, a motivation for its use can be to reduce risks of hospital-acquired infection, delirium, and deconditioning (*Bringing Hospital Care Home*, 2022). A review of evidence that included studies focused on older patients as well as others suggests that "most outcomes, including mortality, are probably at least equivalent to those of inpatient care, while subsequent admissions to residential care may be lower," with more success among interventions at home that supported patients in managing their own care (*Bringing Hospital Care Home*, 2022).

Considerations and Challenges

Though there is great potential for digital technology to enhance health, independence, and convenience, there are a number of challenges and considerations involved in the adoption of in-home healthcare and monitoring technologies. We divide these into challenges related to suitability of the home, older adults' experiences of aging in place, and caregiver burden.

Suitability of the Home

The first set of challenges relate to the quality of housing occupied by potential beneficiaries of digital technology. Millions of older adults live in substandard homes, pay so much for housing relative to income that they cannot afford sufficient food or healthcare, and/or have no access to the internet. These housing-related challenges limit the extent to which technology can be used in the home or may limit its effectiveness. They also present their own health risks to older adults and caregivers. For example, substandard housing can result in increased risk of physical injury or falls.

Though the digital divide has received increased attention, other barriers posed by the physical house itself are often overlooked in health policy discussions. Due to systemic factors, people of color, immigrants, those with disabilities, and low-income households—many of whom also lack adequate access to healthcare—are especially likely to suffer housing challenges. Older adults living in lower-quality housing, who may have greater need for health

services (including as a result of their housing), may be paradoxically less likely to make use of technology that can promote their health and wellbeing.

The Digital Divide

Many telehealth and monitoring technologies rely on a resource that not all households can access: the internet (Lee & Coughlin, 2015). US Census data from 2019 shows that 18 percent of adults 65 and above did not have internet access pre-pandemic (Amin et al., 2020); shares without broadband are estimated to be far higher (Older Adults Technology Service, 2021). Possession of technology itself, like tablets and smartphones, is lower among older adults, even though age-related gaps are narrowing. According to a 2021 Pew Research study, 61 percent of people age 65 and over reported owning a smartphone compared to 96 percent of those aged 18-29 (Faverio, 2022).

Recent data shows that the digital divide has affected some racial and generational groups more than others. Older adults at or below the poverty level are more likely to lack access. In 2018, over 40 percent of this group lacked internet access (Swenson & Ghertner, 2020). Soon after the onset of the COVID-19 pandemic, a survey of service coordinators in senior affordable housing revealed widespread barriers to online services. Only 23 percent of coordinators said that most or all of their residents had reliable internet, and an even smaller proportion reported many of their residents were technologically equipped to make video calls (Ellison-Barnes et al., 2021).

There are disparities by race and ethnicity as well. In 2019, Black and Hispanic older adults were less likely to be able to use the internet in their homes compared to older adults as a whole (Amin et al., 2020). Black and Hispanic Medicare beneficiaries were also less likely to have devices which connect to the internet, as were Medicare recipients with disabilities (Roberts & Mehrotra, 2020). Some of these barriers are not restricted to those over 65: people of all ages who have disabilities are also significantly less likely to own a desktop or laptop computer or a smartphone compared to those without disabilities (Perrin & Atske, 2021).

Even among households with one or more digital devices and some internet access, video telehealth visits and in-home monitoring systems may tax available bandwidth. A

household's internet speed varies based on the number of users online and the types of activities they are conducting (Asher et al., 2021). At a macro level, older housing, availability of broadband infrastructure, and gaps in internet service provider coverage may further restrict internet usage (Asher et al., 2021; Chao et al., 2020). These structural issues particularly impact residents of multifamily public housing, rural communities, and low-income urban neighborhoods.

Finally, older adults have varying levels of comfort with technology. During the COVID-19 pandemic, lack of familiarity with technology impeded adoption of new online procedures and resources among some older adults (gonzález-rivera & Finkelstein, 2021). Research has shown that a user's perception of whether a new device or software is a good "fit" depends on technological compatibility – in terms of both needs and lifestyle – connectedness, and reliability (Liu et al., 2016; Marikyan et al., 2019). The importance of reliability may be heightened for health-related devices and software since they perform critical functions. In addition, for groups who have historically been underserved by health systems and institutions, adoption of smart home devices may require additional trust-building efforts from authorities (Chung et al., 2016). Another concern is the functionality and accuracy of technology in the home when there are multiple users, including spouses (FakhrHosseini et al., 2020).

Some of these barriers could lessen over time as currently emerging technologies become more familiar and baby boomers, who may be more at ease with smart devices, increasingly enter the above-65 cohort. However, groups with fewer resources are likely to be left behind unless care is taken to ensure access, affordability, and education for new technologies.

Accessibility of the Home

Digital technology may prevent and treat immediate health risks and problems, but it does not necessarily tackle the potential health impacts of inadequate housing, such as unsafe conditions or lack of accessibility for those who need it (Molinsky et al., 2019). These factors may limit the ability of new devices and software to improve older adults' health.

Many older adults live in homes that do not support their functional abilities relating to mobility (e.g., climbing stairs and walking), seeing, hearing, self-care, or independent living. Indeed, very little of the nation's housing stock has even basic accessibility features (Bo'sher et al., 2015; Joint Center for Housing Studies, 2014), and data from the 2019 American Housing Survey reveal that many older adults have challenges entering, navigating through, and using different areas of their homes (Scheckler et al., 2022). Other research documents a shortage of appropriate, accessibility-enhanced units compared to the number of older adults with disabilities (J. Kim, 2021). These difficulties can present not just inconveniences but also safety hazards; for example, poor lighting may pose risks to someone with low vision, while a long flight of stairs needed to access a bedroom may create an unsafe situation for someone with mobility difficulties. Architectural barriers that make it difficult for people to come and go easily from their homes can also lead to isolation and loneliness—both of which pose their own health risks (Celiero et al., 2017; Newall & Menec, 2019; O'Luanaigh et al., 2012; Perissinotto et al., 2012; Smith, 2012). Constrained budgets and physical frailty can also make it difficult for some older adults to maintain or modify their homes, adding to safety concerns.

The disparity in access to accessible housing is skewed across demographic groups: Black and Hispanic older adults, plus those not born in the US, were less likely to have homes with accessibility features (J. Kim, 2021) and more likely to report challenges with navigation or use of the home (Scheckler et al., 2022). In addition, compared to homeowners, older adults with disabilities living in rental units were less likely to have housing which met their needs. Accessibility barriers may also affect caregivers' safety and ability to deliver care: for example, for those needing assistance bathing, high-walled tubs present greater challenges for the assistant as well as the older adult than curbless showers do.

Residents of public housing or Section 202 Housing for the Elderly are more likely to have basic accessibility features than other housing occupied by low-income older adults (Airgood-Obrycki & Molinsky, 2020), yet these features are still not universal; moreover, constrained space also affects how well a home can support its occupants. As Pynoos et al. note, "[s]ubsidized housing is…often poorly equipped for caregiving and service delivery," having little space for caregivers to help someone in the bathroom or for a caregiver needing to

stay the night (Pynoos et al., 2008, p. 84). In short, for those who experience difficulty navigating or receiving care in their homes, the utility of monitoring and telehealth may be limited or undermined by the state of the home itself.[7]

Housing Affordability

While difficulties with safety, navigation, and use of the home increase with age, so too do housing challenges related to affordability and stability that can hamper or prevent adoption of smart home technologies. In 2019 over 10 million older households—nearly a third of households headed by someone age 65 or over—were cost burdened, or paying more than 30 percent of their income for housing, and half of these paid more than 50 percent. The incidence of cost burdens rises with age as income typically declines, reaching 35 percent of those 80 and over. Renters and owners who have mortgages on their homes are more likely to be cost burdened, including over 1.2 million renters and 650,000 owners age 80 or above with mortgages.[8] Renters are particularly vulnerable to rising housing costs and precarious housing (Fenelon & Mawhorter, 2020; JCHS, 2019); indeed, 2.24 million older adults faced "worst case housing needs" in 2019, according to the US Department of Housing and Urban development, meaning having "very low incomes" (defined as at or below 50 percent of area median), not receiving government housing assistance, and spending more than half their income on rent, living in severely inadequate units, or both (US Department of Housing and Urban Development, 2021). Housing assistance is not an entitlement, and in 2019 only about a third of older adults with very low incomes received it.

Unaffordable housing can be unstable housing, putting renters at risk of eviction and older homeowners at risk of foreclosure or unwanted moves. Older adults may find themselves doubling up with family (who may also lack sufficient space and resources), in less expensive but suboptimal housing, or prematurely in a nursing home (Doran et al., 2013). Waiting lists for subsidized housing, including those that offer services at home, can be lengthy—again, because

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[7] There may be technical solutions to housing inadequacy, such as small-footprint scooters that reduce the need to widen doorways, or smart home apps that allow someone to control temperature, lights, or window shades with their phone. This paper is focused on health-related digital interventions, but these other technologies can also play a role in supporting older adults aging in place.
[8] Joint Center analysis of 2019 American Community Survey.

housing is not an entitlement program. Accessible and affordable housing is even more limited in availability.

The consequences of housing unaffordability can be dire. The burden of paying off mortgages or monthly rent may cause households to hold back on other important expenses like accessibility improvements and out-of-pocket healthcare expenses (Fenelon & Mawhorter, 2020; Herbert et al., 2021). It can cause older adults to reduce expenditures on food in comparison to those who are affordably housed (JCHS, 2019). New technologies not covered by Medicare may result in installation, repair, and maintenance expenses, further heightening housing costs and increasing disparities (Choi et al., 2019; Marikyan et al., 2019; Peek et al., 2014).

Suitability for Care Provision

Beyond the well-studied challenges listed above, there may be additional barriers to adopting new digital technologies. There is surprisingly little research on the housing preconditions that make remote healthcare in the home successful. In one exception, authors studying hemodialysis found that candidates for conducting the procedure at home and their caregivers expressed a number of housing-related concerns, including worries that the home would need modifications (such as electrical and plumbing changes) to accommodate the dialysis machine, that there was sufficient space, and that loss of electrical power could prove dangerous (Tong et al., 2013).

Similarly, there is little research or information available about housing needs for those receiving post-acute or acute care at home. Authors Clarke et al. noted in a December 2021 evaluation of AHCaH that "using emergency authority, CMS was able to waive hospital CoPs [conditions of participations] for life safety code and physical environment, which allowed for patient care to be provided in an alternate care setting, such as a patient's home for certain approved hospitals." Yet guidance about the patient's home setting from CMS itself or specific hospital-care-at-home programs appears lacking. Under CMS AHCaH requirements, approved hospital programs must be able to respond to a decompensating patient within 30 minutes (Centers for Medicare and Medicaid Services, 2021), which limits the potential areas in which

the program can be used (potentially making it less useful in suburban and rural areas, for example), but baseline requirements for the structure or stability of the house itself appear absent.[9] The implicit assumption that patients have access to adequate home infrastructure, including basic safety features, could potentially block segments of the population from receiving in-home care, or even cause harm if medical systems stall or fail.

Relationship of Person and Home

Operating on the assumption that an older household is stably, affordably housed, with adequate infrastructure that suits residents' physical needs—and also receives in-home care, as required—it is still necessary to ensure that new technologies fit the social needs and desires of older adults. As an evolving array of devices narrows the gap between home and institutional care, we identify critical questions about how technology will affect older adults' relationships to their homes.

Surveillance

The use of monitoring systems may introduce a level of surveillance of the home environment with which residents are uncomfortable. While monitoring technology might support independence, it may paradoxically do so by exposing more of people's daily lives to caregivers and clinical staff. Indeed, studies of older adults' attitudes towards in-home assistive technologies show that privacy was a common concern (Peek et al., 2014). Participants were willing to sacrifice some of their privacy only if the benefits outweighed the costs.

For some older adults, concerns over privacy may involve feelings of stigma and loss of dignity (Mortenson et al., 2016). Users of wearable technology may associate its use with their own vulnerability and frailty (Aceros et al., 2015). Technology might also blur the lines between home and the outside world. While the home has long served "as a key locus for distinguishing

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[9] For example, Johns Hopkins Hospital at Home program, as described on its webpage, discusses patient evaluation, transportation home, and daily visits, but does not mention any housing precondition that must be met (Johns Hopkins Health Care Solutions, n.d.). In contrast, some documents and research on discharge from inpatient settings do mention the physical setting of the home, such as the potential need for modifications (CARP Collaborations and Gana Consulting, 2021; Waring et al., 2014).

between the public and private" (Shapiro, 1998), smart homes reduce these traditional barriers of place and extend an individual's experience of home into any number of other circumstances, such as a medical office, a call center, or the home of a relative. Without adequate transparency and consent processes to govern questions such as what information is captured and when, with whom information is shared, and how information is managed and stored, this expansion of home boundaries could easily violate an older adult's sense of privacy or sense of autonomy in their home (Chan et al., 2022; Liu et al., 2016; Marikyan et al., 2019; Peek et al., 2014). In addition, addressing issues of data privacy and consent may be more difficult or complex for those with cognitive impairments (Kang et al., 2010). Lastly, as with other technologies involving personal data, data security is another concern expressed by potential users of connected technology (FakhrHosseini et al., 2020). Broadly, data management and security is a pressing public conversation that extends widely beyond healthcare in the home and needs to be shaped through legislation and policy.

Changing the Meaning of Home

Research has shown that older adults' sense of identity and autobiography are interwoven with their residential setting, particularly after long residence. As Rowles and Ravdal (2002) note, "Over time, emotional ties to place grow in strength as individual locations accumulate layer upon layer of meaning from the events that transpired within them" (page 92). To these authors, the desire to age in place is a natural outgrowth of connection to one's home and its surroundings, and the "presumed need for the familiar…as adaptive features of aging" (page 90). Technology that is explicitly touted as supporting "aging in place" may inadvertently upset the impetus for remaining in one's home by erasing the physical boundaries that separate the interior domain of the resident and the outside (Mortenson et al., 2016).

Another concern is that digital technology and equipment for monitoring or medical treatment may "medicalize" the home, altering the affirming associations people have of their residence, with all its memories and associations, to a less familiar space that reminds people of illness through the presence of hospital beds, monitors, etc. (Arras & Dubler, 1994). This may be true for the person receiving treatment or virtual healthcare at home as well as a spouse or

visiting family. In a review of 24 studies involving 214 people receiving hemodialysis at home, researchers found some patients felt that "dialysis turned the home into a medical environment" and that this could be a continuing reminder of illness and off-putting for family and guests (Walker et al., 2015).

Regulation of the Home

Another issue of concern, particularly for the delivery of acute medical care in the home, is how regulators will perceive the residential environment. Our research has found little guidance for hospitals or other care providers about the importance of the physical home environment and none about its affordability or stability. (Indeed, as noted earlier, CMS lifted environmental regulations pertaining to the hospital to facilitate the expansion of acute care at home, without mentioning any preconditions of the home.) As digital technologies evolve, were CMS or another agency to impose regulatory requirements on the home environment, these could conflict with cultural sentiment and legal precedent about domestic privacy. Yet to ignore the suitability and complexity of the home presents its own problems. And both sides—regulating or not regulating—have equity implications, since the homes most likely to be unsuitable for home care are occupied by groups more likely to experience disparate/systematic health challenges.

Burden on Caregivers

While technology can reduce the need for in-person care or support, there is also a concern that it will place additional burdens on caregivers. Many older adults need assistance using technology because of their cognitive decline, sensory challenges, or lack of experience and training using digital devices. Hospital-at-home programs raise concerns about caregiver burdens as well. Though current acute-care-at-home programs typically require daily in-person and virtual visits from a professional care team, the patient is likely not otherwise professionally assisted in their home, leaving unpaid caregivers to provide a watchful eye or respond to emergencies.

Acute-care-at-home programs will need to assess, in an ongoing way, not only the needs and capacity of the older adult, but also the needs and capacity of the informal care provider. A 2022 paper on acute-care-at-home noted that research on cost effectiveness has so far focused mostly on savings to health services rather than society, omitting financial burdens on patients and families, and that these can be substantial (*Bringing Hospital Care Home*, 2022). Families will need financial support to cope with the economic hardships of providing unpaid care. Caregivers, many of whom are "on call" 24 hours a day, will need respite care as well as social and mental health resources. And with increasing reliance on technology to manage complex health situations at home, family caregivers will need training to use devices, follow protocol, and provide quality care. Communication will be key to integrate family caregivers into the health care team and ensure correct implementation of health routines by people without formal medical training.

Discussion

We have noted three broad sets of housing-related challenges regarding digital technology to support older adults living in the community, as summarized in Table 2. The first set relates to housing challenges that can prevent or impede the utilization of digital technology, such as lack of internet connectivity or accessibility features in the home. Housing challenges—including physical inadequacy, unaffordability, and unstable living situations—also negatively affect health, so while monitors and emergency alert systems can support wellbeing, the very setting in which these are used may be simultaneously damaging health. The second set of challenges relates to ways in which digital technology may change older adults' perceptions of and feelings about their homes, and about themselves. Finally, the third set relates to the potentially underappreciated burden on caregivers.

Table 2: Challenges and Equity Concerns of Digital Technology for Aging in Place

Challenge		Description	Particularly affects...	Impacts adoption of...
Suitability of the Home	Digital divide	• Inability to use technology due to lack of internet, devices, experience • Technology may be usable but less effective where there is less reliable internet service or little training/assistance	Lower income/wealth, older generations, rural residents, affordable housing residents, urban communities of color	Systems and software for monitoring, telehealth, and telemedicine
	Housing adequacy and accessibility	• Inaccessible or substandard housing poses hazards to older residents despite technology supporting health • Inaccessible or substandard housing poses hazards to caregivers • Housing may not provide adequate space or features to support technology	Lower income/wealth, renters, older adults with disabilities (disproportionately people of color), older adults with acute needs	Telemedicine and "hospital-in-the-home" in particular, although monitoring and telehealth could also be affected
	Housing unaffordability and instability	• Unstable/loss of housing results in unwanted or forced moves, affects health, and disrupts use of technology • Housing affordability challenges may negatively affect health in ways that cannot be addressed by technology, e.g., cutbacks on food due to financial concerns • Unaffordable housing impedes ability to pay for internet, smart devices, software	Lower income/wealth, renters, older adults with acute needs	Telemedicine and "hospital-in-the-home," in particular, but also other technologies
Privacy and Meaning		• Fears about loss of privacy, feeling home has become medicalized and associated stress or anxiety can have negative health effects • Surveillance may decrease rather than increase sense of independence • Lack of informed consent or control may negatively impact relationships with other household members, remote caregivers	People with cognitive impairments, older generations	Hospital-at-home and monitoring systems

	• Medicalization of the home could make it less comfortable for residents and limit social interactions		
Caregiver Burden	• Shift away from institutional care puts pressure on already strained care workforce, increasing likelihood of unfulfilled needs or decreased quality of care • May increase burden on family caregivers, leading to financial issues and burnout • Those without access to professional or informal care may not be able to access technologies and associated health benefits	Lower income/wealth, isolated older adults	Hospital-at-home and monitoring systems

As noted in Table 2, there are extensive equity considerations that must be incorporated into the design, delivery, cost, and regulation of digital technology. Policymakers and practitioners must acknowledge the challenges that many already face in navigating and maintaining their homes, as well as with accessing needed supports and services. Some problems, such as a lack of broadband infrastructure or internet service provider coverage, affect whole communities. Due to structural discrimination and its associated impacts, these barriers to safe, affordable, connected homes disproportionately affect older adults of color, immigrants, and those with disabilities, among other groups. Any comprehensive approach for technologically enhancing people's homes must be accompanied or preceded by attempts to fix these issues and provide all older adults access to a basic standard of housing.

As payers, regulators, and providers adapt their policies to the changing landscape of digital technologies in the home, building toward a "health care delivery system without walls" with the home at its core (Ritchie & Leff, 2022)—and as innovators continue to iterate and improve the technology—it is critical that all involved see the home as more than a box in which care and support occurs. Monitoring and healthcare aids may increase older adults' independence and improve their wellbeing, but it also transforms the home environment in potentially undesirable ways for both the patient and for other residents of the home. To ensure these tradeoffs are worthwhile, older adults should exercise understanding of and

control over technologies which are implemented in their places of residence. In-home monitoring and healthcare devices, implemented in appropriate and tailored ways, can increase convenience, comfort, and independence for older adults. This could bring about more opportunities for enjoyable and engaging activities, and a greater span of control, thereby enriching their lives.

Finally, the fields of healthcare and housing must collaborate more comprehensively. Professionals in both fields should be given opportunities, incentives, and training which will allow them to work more closely together to design and deploy technology that truly takes into account the settings in which it will be used. Indeed, there is the potential for telehealth and acute-care-at-home programs to provide medical providers a window into potential dangers in the home or lack of other types of resources (e.g., food) (Gorbenko et al., 2023), though this is of value only if practitioners can deploy resources or referrals to help address those issues. Healthcare and housing systems can also benefit from research that specifically explores the use of technologies in the homes of people with housing challenges, such as inaccessibility or unaffordability. In the spirit of promoting a more equitable future, these shifts will allow in-home technology solutions for monitoring and healthcare to be more flexible and inclusive.

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