The future of aging in smart environments: Four scenarios of the United States in 2050

Lauren Withycombe Keeler *, Michael J. Bernstein

School for the Future of Innovation in Society, Arizona State University, Tempe, AZ, USA

A B S T R A C T

The population of the United States is getting older. Unlike other countries with aging populations, however, the state of aging in the United States is in crisis. Healthcare and social reforms will likely be necessary in the coming decades to address structural issues with retirement, socioeconomic inequality, and the high cost of healthcare. In the meantime, AI-enabled smart technologies and environments are being rapidly developed to assist overwhelmed caretakers, enable access to healthcare providers, address isolation and depression among older adults, and provide mobility to and from essential services in sprawling suburbs and rural areas. This study utilizes a participatory, intuitive logics approach to construct scenarios of aging in smart environments in 2050 that illuminate the uncertainties, challenges, and opportunities presented by the coming confluence of two mega trends: an aging population and increasingly sensed people and environments. The results include four scenarios including descriptions and key features, and with narratives available in the appendix. In the discussion, we reflect on five provocations distilled from expert interviews to illustrate what aging might look like in 2050 from a variety of socioeconomic vantage points and mediated by technological capabilities and arrangements born of differing policy, economic, and societal conditions.

Introduction

In 1960, developer Del Webb introduced the United States to a suburban, distinctly 20th century, vision of retirement. Sun City, located west of Phoenix, Arizona, offered white, middle class Americans over 65 a home in the sunshine, next to a golf course (Trolander, 2011). The vision of age-restricted communities for so-called "active adults" mirrored a cultural shift in the post-war American West toward suburban, air-conditioned, insular, and autonomous-seeming master-planned communities. The Sun City mirage belied the technological marvels and social restrictions making "the good life" in the desert possible. Between 1942, when the US Social Security program went into effect, and 1962, when Del Webb graced the cover of Time Magazine, the model of American retirement transformed from simply a point in time when one ceased to work to an aspirational, multi-decadal phase of life complete with new infrastructure and social arrangements (Costa, 1998; Martin & Martin, 2005; McDonald, 2013).

Today, reality asserts itself ever more strongly on the American imagination. Age-restricted oases like Sun City, which, in 2018 had approximately 39,300 residents and was 92 % white, offer fewer and fewer spaces, and; the pathways in rise ever steeper. In a testament to the toxic potency of the American Dream in capturing many peoples' imaginations about the US and what it means to age here, there are 3 times as many older adults living in poverty than living in age-restricted communities. The year 2019 saw 13 % of

adults over 65 living in poverty (annual incomes less than $11,756), 26 % among adults over 75 (compared to an OECD average of 14) (OECD, 2018, 2019a; UNDESA (United Nations Department of Economic & Social Affairs), 2017) and 42 % of older adults under 200 % of the federal poverty line (the figures are even more disconcerting among BIPOC[1] communities) (Cubanski, Koma, Damico, & Neuman, 2018).

Aging in US society is in crisis, no matter how loudly the American Dream sings its Siren song. Older adults and caregivers (formal and informal) suffer disproportionately the gross indignities from this crisis, whether from health-system failures at sites of care, the rapacity of health system businesses, wanton disregard for or of health workers and system function, or the timidity of most government leaders in advancing solutions.[2] These indignities are compounded by higher levels of loneliness and social isolation (with significant comorbidities), and reduced quality of life among older adults (Freedman & Nicolle, 2020; Santini et al., 2020). Long-term concerns over the roots and potential consequences of this simmering societal challenge are not new and they implicate social systems already burdened with reconciling shortfalls in various welfare protection systems —(c.f., Morbidity and Mortality Weekly Report (2003); National Research Council, 2012). Ignoring the plurality of futures facing older adults in such drastically different circumstances precludes the ability to problematize and thus address the complexities that need navigation to advance the welfare of these populations in the future (Cozza, Crevani, Hallin, & Schaeffer, 2019).

Seeing that the past and present of aging in the US seem neither just nor tenable—particularly if by 2050, the number of Americans over 65 doubles as predicted (from 43.1 million in 2012 to 83.7 million and increasing as a percentage of the population from 13 to 20 %) (Ortman, Velkoff, & Hogan, 2014)—how might the future of aging look in the United States?

In this paper, we explore the future of aging in the United States in 2050 at the intersection of a new and potent 21st century vision of interest: the smart environment. Smart environments refer to ecosystems of implants, devices, and places that utilize sensing technology, large data sets, monitoring, and artificial intelligence to augment human and environmental capabilities (Cook & Das, 2004; Poslad, 2011; Rashidi, Cook, Holder, & Schmitter-Edgecombe, 2011). Such technologies are increasingly advanced as a way to realize more sanguine futures (DesRoches and Taylor, 2018; Sadowski & Bendor, 2019). For better or worse, the proliferation of internet connected devices and advances in computing power, have changed how people work (Langensiepen, Lotfi, & Puteh, 2014), access healthcare (Dhaka & Johari, 2016; Khosla, Chu, & Nguyen, 2013), move around their communities, socialize (Atzori, Iera, & Morabito, 2011; Sáez-Martín, Haro-de-Rosario, & Caba-Perez, 2014), and participate in democracy (Kumar, 2017; Pournaras, 2020; Walters, 2011)). While the COVID-19 pandemic has accelerated a trend toward remote work and online socialization (Brynjolfsson et al., 2020), the isolation and stress of the pandemic have contributed to rises in suicides, alcohol and drug use, and depression among people of all ages (Palgi et al., 2020). For older adults, this has exacerbated existing high levels of isolation and depression (Santini et al., 2020).

Digital connectivity through "smart" devices–networked devices that engage in device-to-device communication aided by machine learning and artificial intelligence (Fodor et al., 2012)–has been presented as a solution to isolation (Reis, Paulino, Paredes, & Barroso, 2017). Indeed between 2000 and 2019 internet usage among adults 65+ has grown from 14 % to 73 % (Pew Charitable Trust, 2019). But as current events continue to reveal, smart technologies do not resolve the underlying social dimensions of societal issues. Further, as Flick, Zamani, Stahl, and Brem (2020) elaborate, deployment of ICT for health and aging implicates a range of ethical and social concerns often ignored, for example homogenous stereotyping of older adults as users; accounting for responsibility and liability if humans are divorced from ICT-delivered care; and issues of application and abuse of sensitive health data. Indeed, the promise of "smart" technologies presumes the existence of a robust healthcare system, social safety net, and technologically literate and socially connected public – complex sociomaterial realities (Cozza et al., 2019) – evidence of which, as reviewed above, is far from ubiquitous even in the present. We explore the collision of the above mentioned demographic transition with the earnest and accelerated efforts to technologically innovate out of human and institutional failures in an attempt to "get smart." Through five provocations and four future scenarios, we interrogate and broaden the horizons of aging and demographic challenges in the context of advancing and emerging technologies.

Method

We developed four Future of Aging in Smart Environments scenarios for 2050 using a participatory, intuitive logics approach (Chermack, 2011), described in detail below. Following Linstone and Turoff (1975), we first sought to integrate diverse expertise to inform scenario development. To do so we employed a non-probability, purposive sampling strategy to identify experts to contribute to the scenario development. Inclusion criteria for participation included expertise relevant to futures, aging, smart technologies, technologies for aging, and cities. Integration of diverse expertise, including "disruptive" or "non-linear" thinkers is important to participatory scenario development and the goal of constructing futures which are both embedded in best available knowledge and significantly divergent from the current state (Keeler, Bernstein, & Selin, 2019; Selin, Kimbell, Ramirez, & Bhatti, 2015). While there were no explicit exclusion criteria, the research team sought to identify diverse expertise among those who met inclusion criteria,

---

[1] BIPOC is an acronym for Black, Indigenous, and People of Color.
[2] See for example the Pulitzer Prize award-winning investigative reporting by ProPublica on Health care, available here: https://www.propublica.org/topics/healthcare, with specific series like: "Health Insurance Hustle" available here: https://www.propublica.org/series/the-health-insurance-hustle; "Patient Safety" available here: https://www.propublica.org/series/patient-safety; "When Caregivers Harm" available here: https://www.propublica.org/series/nurses; "Dollars for Doctors" available here: https://www.propublica.org/series/dollars-for-docs; "Nursing Homes" available here: https://www.propublica.org/series/nursing-homes.

without over-representing a single expertise. Our purpose in holding these conversations (n = 27) included: a) gathering perspectives on potential attributes of, drivers, and uncertainties related to the future of aging and smart environments; b) enhancing our understanding of the unique points of view of attendees; and c) creating an opportunity for participants to ask any questions about the project and event. After each 30-minute interview, the interview team reflected on the unique perspectives and tensions surfaced in the course of conversation. We distilled and synthesized a range of thematic provocations, subsequently presented to participants in a pre-workshop reading which invited participants into the contested future space where individual and collective interests, social and technical inertias, and dreams and ideals converged.

The scenario workshop itself occurred over 2-days, in-person, in January 2020. Fields represented in the scenario development included: medicine, gerontology, public health, AI, robotics, science and technology studies, science fiction, chemistry, business, and journalism, as well as youth representatives. Through facilitated plenary and small group discussions, participants identified driving forces, selected two drivers to serve as axes for the scenarios, identified key scenario features, developed narrative outlines to illustrate the scenarios, and developed an initial set of implications for the scenarios. These results were refined by the research team and further vetted by participants, who reviewed and provided comments on a draft report. A final report was then compiled and shared with participants prior to the writing of this article (Keeler & Bernstein, 2020).

The results of this exercise include a set of provocations, derived from preliminary interviews, which we summarize below and which were input to the workshop to promote divergent thinking among participants. Following the provocations, we present four scenarios of aging in smart environments in the U.S. in 2050, including descriptions and key features. We then offer an analysis across the scenarios to illuminate additional tensions and support present-day planning for more viable and just long-term futures.

Results

From interviews with experts across disciplines and professions we below synthesize a set of provocations which distill essential uncertainties affecting aging in the smart environments of 2050. How these uncertainties play out over the next three decades will greatly impact the lives of aging adults in the United States, and their loved ones. The scenarios and discussions that follow offer plausible responses to these provocations, disciplined by critical uncertainties identified in plenary, during the two-day scenario workshop.

Provocations on the future of aging in smart environments

The potential substance of a future wherein demographic shifts have fully played out, along with attendant consequences, is uncertain. New limits of human age and the number of older adults may introduce new frontiers for science, policy, family life, and religion. Yet even today with clamoring calls to "conquer death" (Friend, 2017) and press beyond previous bounds of human lifespan, questions of equity and justice go begging: "whose lives?"

How will intergenerational relations fare?

Will the intergenerational distrust and resentment, captured in the "okay, Boomer" meme (Wagner & Luger, 2020), further divide society along generational lines? Shared senses of respect, responsibility, or appreciation may have drastic effects on the ability of any future society to mobilize political will and care resources to address challenges associated with aging in smart environments. People in sandwich generations—adults responsible for not only childcare but also parental care—may find particular burdens difficult to bear, with implications for associated policies, businesses, and design of human environments. Alternatively, many may find themselves grandparent-less, having to navigate different unique challenges of care, learning, and forging a life without having direct access to inherited wisdom. These challenges may be made more complicated by where and how older adults will choose or be able to age——independently, in communities, with families, etc. (Miller, McDaniel, & Bernstein, 2021)

How will people connect to one another and their environments?

The capability, availability, and role of technology integrated into human environments and care settings is uncertain. Technological connectivity in our sensed environments is altering the real and potential ways people interact, age, and experience and receive health care. By 2050, some implications of the rise in sensing, connectivity, and their infiltration into so many parts of life, will be clear; others offer only hints regarding their consequences. Technology enabling connectivity of devices supported by more advanced networks, like 5G, may exist ubiquitously and enable download speeds hundreds of times faster than current technology (OECD, 2019a). Modes of production and logistics attending such connectivity may be further transformed by digitalization and additive manufacturing capabilities (OECD, 2017a, 2016b; OECD, 2017b). 3D printing serves as an illustrative example here, potentially enabling paradigmatic changes in production of functional parts to casting and tooling components. Applications may extend to food, medical, and a range of other more day-to-day accessible materials. Future additive manufacturing methods might account for reduced production greenhouse gas emissions, air pollutant, material toxicity, resource scarcity, recyclability / circular life cycle, energy and other factors. Supported by more integrated, high-speed networks, cloud-computing and more massively data-enabled decision--making could further alter production methods, organizational forms, productivity, and the role people play in industries (see for example, prelude experiences with automated machine tools, Noble, 1978). Still, the paths along which such developments unfold are subject to social and political determination.

What will we do with all the information gathered through sensing?

Means of making sense of information may be drastically augmented by artificial intelligence applications (AI). AI functionality may depend on large volumes of digital and historical data, as well as the quality of such data and algorithm integrity. Uptake of AI today is visible across a range of areas in society, including and surpassing, "transport, agriculture, finance, marketing and advertising, science, healthcare, criminal justice, security, the public sector, as well as in augmented and virtual reality" law, education, and beyond (OECD, 2019b, p 47). The convergence of enhanced connectivity, altered modes of industrial production, and AI-assisted decision-making may enable further paradigmatic shifts in technology development as well as healthcare delivery. As an example, autonomous vehicles, outfitted with hosts of sensors, processing capacity, monitoring, computer vision and detection systems, may advance to level five in the Society of Automotive Engineers (SAE) standard of drive without human intervention (OECD, 2019b, p. 51). Functionality at this level would depend upon geographic mapping detail and other accompanying road and satellite infrastructure, as well as associated legal and regulatory issues (c.f., Federal Ministry of Transport & Digital Infrastructure (FMTDI), 2017). On the healthcare front, AI-enabled advances in personalization of healthcare with genome editing might enable tailored interventions, after clearing certain ethical, scientific, and regulatory issues related for example to off-target and environmental impacts (National Academies of Sciences, Engineering, & Medicine, 2016, 2017). Examples here may include diagnosis and treatment in non-reproductive cells (skin, liver, lung, heart), with specific applications from cancer treatment to muscular dystrophy and other areas (National Academies of Sciences, Engineering, & Medicine, 2018; Garden & Winickoff, 2018). It remains to be seen who will have access to these life-saving treatments and life-altering technologies.

How well will innovation in smart technologies and environments serve the needs of older adults?

The role older adults play in innovation processes to develop technologies ostensibly for their benefit will affect how well those technologies serve their needs. Also, digital natives may experience future technology differently than digital immigrants do, which may shape responses to the challenges of future smart environments. Related, people and societies may need to more seriously grapple with questions of meaning and purpose in human life as automation decreases the need for certain forms of labor and as people have

Fig. 1. Four scenarios of the future of aging in smart environments workshop, located within the social integration (Y) and individual choice (X) axes. Image and illustrations by Bryan Rauch & SHERPA, LLC with permission.

the potential to realize longer, healthier lives. This is particularly salient in the United States where work is maintained as a hugely defining life feature. Accompanying such reflection may be a vast re-thinking of when and how we educate ourselves, experience a career, and move into post-career phases of life. Simultaneously, healthcare systems in such futures may look significantly different. Will companies and the societies in which they operate remain incentivized to develop treatments for illness or improve prevention, care, and well-being? Non-trivially, the question of "why sense?" may also change as capability to sense, not only for symptoms but also preventative indicators, develops. Considering how technology is deployed in such systems—as replacement or supplement to human care—will also drastically impact lived experiences and entail emergent consequences.

How will policy and politics shape the social and technological landscape of the future?

Policy and business implications abound related to data ownership and privacy; healthcare policies; and whether and how such policies relate to employment, data, food, transportation, and housing policies. The structure of policies—public or private sector (and whether such distinctions remain meaningful)—will affect the answers to questions of where people may afford to age and receive care, as well which technologies they may be able to benefit from in the future. With increasing use of sensing and algorithms to delineate normal and baselines from "intervention-worthy" signals, the question of how "normal" is defined may become increasingly important. Defining "normal" has consequences for a larger, diverse population. If assistive technologies are designed for wealthier older adults, this may have unintended, undesirable consequences for the larger majority of the adult population.

Scenario scaffolding: Critical uncertainties for aging in the smart environments of 2050

The Future of Aging in Smart Environments scenarios are scaffolded by two axes, depicted in Fig. 1, representing critical uncertainties affecting the future of aging in smart environments between now and 2050. On the x-axis are two alternatives for individual control over the technological choices available to aging people in the future. On the y-axis are two alternatives for social integration across generations. These uncertainties were identified by experts in the workshop as being particularly impactful on the lived experience of aging people and as playing an important role in determining the distribution of risks and benefits of smart technologies.

The critical uncertainty on the x-axis asks, "What kinds of smart technologies are available to aging people in 2050, are there many options, or only a few? And why is that?" Consider the number of options one has for laptops. It is a highly competitive space with options of widely varying quality available for a variety of needs and budgets. Now, consider the options one has for internet service. In the United States you have one, possibly two options, dictated by geography and very little flexibility in price and service, with two companies controlling half of the entire market (Mitchell, 2021). Will smart technologies of the future be numerous and generated from a highly competitive space, requiring technological literacy for each smart device in one's home and body? Or will a few companies dominate the market, with choice architecture predetermined by monopolies or tightly regulated marketplaces? Will smart technologies be like laptops or like internet service? And what kinds of options will be available for those who want to opt-out of the kinds of pervasive monitoring technologies that populate the scenarios? One alternative on the x-axis, called "High Technological Choice" in Fig. 1, views smart technologies as more like laptops in 2050. With this alternative, smart technologies abound for home, body, and environmental applications, and choices available are of wide-ranging cost and quality. This is a more open innovation system, with many opportunities for diverse actors, including bad actors, to take part in innovation processes. The breadth of this landscape might entail many choices for devices to aid in the monitoring of one's health, behavior, relationships, or environment. However, such abundance could tend toward generating a tyranny of choice wherein high degrees of technological literacy are required to discern appropriate technologies to use, when, and how. AI may feature as a potential decision aide for the overwhelmed, supported by some thirty years of substantial data collection on the population to hone data-driven approaches to health, behavior, relationship, and environmental monitoring. In "High Technological Choice" futures you may see people opting out of technologies because of decision fatigue or a lack of trust in the quality of technologies or the security of the data they collect. You may also see vibrant DIY and hacking cultures that manipulate available technologies to suit individual needs, and subvert any monitoring mandates imposed by companies, families or the state.

The contrasting endpoint on the x-axis, called "low technological choice" in Fig. 1, views smart technology in 2050 as more like internet service provision. In this case, a considerable choice architecture, arbitrated at a group rather than individual level, constrains selection of technologies to occupy bodies, homes, infrastructures, and environments. Such groups might include government, private insurance companies, and corporations, among others. Choice architectures would mediate the kinds of technologies available, and could, for example, require that smart technologies meet certain standards, be sold at certain prices, or realize other societal benefits. With greater constraints on choice there is a risk that large technology monopolies persist. At the same time, centralization, monopoly or otherwise, could enable greater integration and analyses of large data sets gleaned from smart technologies. From this perspective, "low technological choice" may feature data-driven approaches to health, behavior, relationship, and environmental monitoring seen to be accurate and widely used, but subject to surveillance for commercial, public health, policing, and other purposes. In "low technological choice" futures it may be more difficult for people to simply opt out of technologies, because choice architecture may be determined by the state or an employer and may come with stringent monitoring requirements. This may lead to more flat-out rejection of technologies than seen in the high technological choice futures. If people feel technologies cannot be tailored to suit their needs, and are being used to advance someone else's interests besides their own, it may lead some to feel the benefits do not outweigh the risks, particularly when the state and social services are weak.

This second critical uncertainty, on the y-axis as "social integration across generations," asks where does aging occur in the social, cultural, and geographic landscapes of the United States in 2050? The question probes at attempts to reconceive, revive, and reconcile Del Webb's vision of retirement given 21st century realities. The first alternative called "high social integration" in Fig. 1, envisions

older adults aging, "in plain sight," integrated into families and communities and reflecting a view of aging as more gradual continuum than rigidly phasic. With high social integration as people age they may live with and among other age cohorts, in the workplace, in educational settings, and in housing. High social integration may translate to multi-generational housing, but not exclusively. With high levels of integration and healthspans extending well beyond 65 years of age, people may subsequently seek greater meaning from life through mentoring and social interaction, or work longer to earn income in support of family and healthcare needs.

The second alternative on the Y-axis is called "low social integration" (see Fig. 1). This is expressed as aging apart. In this alternative, as people age, many move to age-restricted communities where they feel more recognized, appreciated, and attended to. Those who can afford it may find vibrant and innovative communities of like-minded people with all the luxuries, advanced technologies, mindful care practices and improved healthspans they can afford. But if socio-economic inequalities persist, those who cannot afford to age this way may find themselves in less welcoming age-segregated communities designed with age rather than individual in mind or in outdated retirement homes that privilege safety, security, and access to a basic, rigid level of care.

Scenario 1: well assisted (Low technological choice + High social integration)

Old age is an aspiration; a time of life that many look forward to. Retirement is less formalized than in decades past, with employment exhibiting a "long tail" as the nature of work slowly changes as people age. While automation has changed the nature of work (Inayatullah, 2017), technology, creative, and education industries grow in the United States, leveraging automation but also expanding their workforces. Older people are highly valued in these industries, for the wisdom they have accumulated over their lifetime, and their first-hand experience with rapid technological change. They offer a knowledge bridge between old systems and new, automated systems. While it is common for aging people to work into their 80 s and 90 s, they often work fewer hours and take on responsibilities that draw on this deep knowledge and experience. Many older people take on more mentoring and consulting responsibilities. Younger people value the experience that older people bring to the workplace, and it is common within organizations for young people to seek out the mentorship and wisdom of aging workers. For those who work in industries where it is difficult to continue employment late in life, families often step in to fill the income gap experienced by their older relatives, offering care and support while also benefiting from childcare, companionship and mentoring offered by opening one's home to aging family members.

Advances in medicine and healthcare, enabled by biometric data collection, monitoring, and integration with smart households and communities, have lengthened lifespans and healthspans (years of life lived free of age-related disease and disability) (Belsky et al., 2015). Middle- and high-income Americans routinely live beyond 100 years.

Personal health data is a public good, and this change coincides with a broad restructuring of healthcare in the United States. While private and publicly-traded companies are still involved in the manufacturing of technologies for personal and public health monitoring, they operate through large, competitive government contracts. New regulations restrict the sale of personal data for profit, though de-identified, large health datasets are routinely used to inform technological innovation, public health policies, and personal health interventions. Individuals and their family members have access to their data and to technological assistance in making sense of that data. Maintaining personal health and the health of dependents is rewarded through tax breaks, lower healthcare costs, and discounts on in-demand technologies and programs that promote wellbeing. Government programs incentivize cohabitation with and caring for older and disabled family members and loved ones to ease the burden of caretaking on caretakers. Individuals are well-socialized in personal and kin monitoring, and it is common practice. For those who find in-home and on-body monitoring invasive or unhelpful, opt-out options are available. However, as people reach 75, increased health and behavior monitoring is required for employment and to be eligible for certain government benefits. For families living in intergenerational households, lifestyles, including food, certain housing options (e.g., smart refrigerators and stoves; single-level, accessible homes), and recreational activities, are increasingly monitored by family members as people age. For some families this causes tensions, particularly when boundaries are not respected. Smart technologies can be tools of care deployed for improved wellbeing, but also of control.

The systems of retirement living and assisted living which characterized "old age" in the U.S. from the 1980s through the 2020s have been dismantled in favor of aging in place, with families, and in multi-generational communities. As care of aging adults increasingly falls to family members and loved ones, there is a tension between monitoring for safety and care and allowing autonomy. (*See supplementary material section 1 for Well Assisted narrative*).

Key features of scenario 1

Lifespans and healthspans are significantly extended.

● Being mentored by an older person is appreciated and viewed as valuable.

People work longer as a result of longer lifespans and healthspans.

● The focus of work in older age transitions actively to fulfillment-based mentoring or consulting, rather than high-income earning.

Government programs encourage increased multi- generational aging in place or in communities as part of a strategy to ease the burden of caretaking and control costs.

● Incentives encourage younger family members and individuals to take active roles in the lives of older adults and people with different abilities.

- Older adults are encouraged to socialize with each other and with younger generations to maintain mental and physical wellbeing. Socialization is monitored for quality.

  Health data are viewed as a public good, abundant, and actively surveilled.

- Personalization comes with active biometric and behavioral monitoring. People are organized into health and risk categories for tracking, monitoring, and making recommendations for improved care.
- There is a high degree of interpersonal surveillance. Monitoring family and even friends is a common practice to improve healthcare performance and retain benefits from various government and industry programs.
- AR/VR enable virtual check-ins with care providers to further improve wellbeing and healthspans of older adults.

  The ability to make sense of large amounts of health data is highly valuable.

- Integration between older and younger generations is commonplace as a result of new social norms; such interactions help ensure translation from data to behavior change for improved wellbeing.

  Multi-generational households increasingly emerge as an economic imperative as older adults earn less from transitions to mentoring and fulfillment.

- Continuing and lifelong education, not only about health and wellbeing but also a wide range of related topics, grow in importance as retirement careers focus more on mentoring and fulfillment.

  Formal mentoring responsibilities, organized by governments and community groups, promote intergenerational interaction.

- Employment is reduced but these mentoring responsibilities can still provide a small supplemental income while keeping seniors regularly engaged in communities they care about.

Scenario 2: how terribly strange to be 90 (High technological choice + High social integration)

To be over 65 in 2050 offers an abundance of technological choices. The marketplace is replete with a constantly updating stream of technologies for self-monitoring and self-enhancement. There is a tyranny to the choice, however – the quality, reliability, resilience, and security of the technologies varies greatly depending on what you can afford and what you know. There are many who have less and who are underserved by the choices available. There is a rich DIY and tech-hacking culture across generations to make technologies more suitable to the needs of individuals. The vast array of smart technologies on and in people and environments has led to the commodification of data for the benefit of the generators. People of all ages sell their data in exchange for access to better technologies, upgrades, or discounts on staples like food and clothing. Most older adults monitor themselves using the biometric and environmental smart technology they can afford; they are not systematically monitored by loved ones, or healthcare providers unless this is requested. In the workplace, however, monitoring is commonplace. Lifespans and healthspans have increased substantially as a result of technological innovations. Higher-income Americans live to 100 or more and middle-and low- income Americans are commonly healthy into their 80 s.

Slowed economic growth, the drag of climate change impacts, and the limits of tech-solutionism have brought social connections and fictive kin relationships, elective familial relations, to the foreground. Strong family and community connections are non-substitutable buffers against the vagaries of job changes, health problems, and day-to-day stressors. Aging people live in multi-generational households, in shared houses with friends and partners of all ages, or in their own homes within multi-generational communities. Life and health extension is a contributor to the economic imperative of continued employment, along with retirement's demise. People work well into their 80 s and even 90 s in part-time, white-collar and service jobs, although frequent job changes are common. The employment of older people provides much needed income to multi-generational households. People learn in many different ways and settings throughout their lives to satisfy their evolving work and personal growth needs. (*See supplementary material section 2 for How Terribly Strange to be 90 narrative*).

Key features of scenario 2

Lifespans and healthspans are significantly extended.

- Younger generations grow-up expecting good health throughout and to the end of their lives; already-older cohorts' receipt of life-extending practices only later in life exacerbates intergenerational tensions.

  Older adults work longer by choice and necessity; job profiles across the lifespan have evolved to suit this trend.

- With a new multi-generational workforce has come novel and more elaborate opportunities to retrain throughout one's life to ensure continued employability.
- Tensions related to employment opportunities across generations are more common.

Ownership of health-related data is enshrined for the individual, creating new sources of personal wealth and new markets for personal health data.

● Breakthroughs in precision longevity care, powered in part by more advanced health-data markets, provide additional benefits to those with the necessary means and data histories.
● Younger people do not routinely monitor older generations without prior consent.
● Data are constantly generated by people living their lives amidst smart technology. These data have been commodified and serve as a means of exchange.

Technological literacy is more important than ever; abundant technological choice means that one benefits from heightened awareness of one's own technological needs.

● Mind-altering drugs and body-altering holographic technologies allow people to mentally and physically take on different forms to suit learning and career changes in the course of their lives.
● The abundance of technological choices can be overwhelming but is sometimes navigable with the help of AI.
● Benefits of technological enhancements are not universally realized; income and wealth determine who benefits from the increasingly sophisticated and personalized technologies available.

People live together in multi-generational and peer communities, sharing physical and digital spaces.

● Enhanced integration provides essential quality of life improvements for individuals, as well as safety and security.
● Mobility assistance, including AVs and drones, move people and products around cities.
● Homes vary significantly by geographic location in response to the wildfires, strong storms, floods, and droughts that are a routine part of life.

Scenario 3: Live Free & die Free (High technological choice + Low social integration)

Older adult living really depends on whether you are in an age-segregated community or not. While people love their own parents and grandparents, values divide dinner tables and communities. Intergenerational tensions persist and worsen. As jobs are lost to automation and climate change wreaks havoc on communities and savings accounts, younger generations come to increasingly regard people aged 65 and older as selfish, stagnant, and out of touch. While there is great promise for improved livelihoods and healthspans for those who are affluent, most aging people in this scenario struggle to stay healthy, social, and cared for.

Affluent older adults move into age-segregated communities. These communities are hubs of innovation and economic development. They are insular, and their focus is on the care and improvement of the lives of aging people. They fund research centers, award fellowships, and offer themselves as test subjects for the latest technologies available to extend lifespans and healthspans. As a result, lifespans in these communities are points of pride, with communities advertising their lifespans to attract new residents. There is a trickle-down of gero-centric innovation to aging people outside of age-segregated communities, but access to these technologies for most aging people lags years behind the affluent.

Outside age-segregated communities, aging people piece together smart technologies and housing solutions that meet their needs. For most people, this means that aging is difficult and often lonely. Low-cost private and minimal public options for self-monitoring are used by older people and their loved ones to stay healthy and predict susceptibility to future illness. For those who can afford early intervention, early diagnosis is a blessing. Most people over 65 are technologically savvy. Everything from healthcare to employment to connection and meaning can be found in vibrant online worlds enhanced by virtual reality and haptic interfaces. These digital environments and social networks offer ways for aging people to engage with each other, generate income, get remote medical attention, exchange knowledge, and remain politically active. Most older adults live outside age-segregated communities, in cities and towns with age-diverse populations that are often discriminatory against aging people. There persists a general sense that older generations did not do enough to prepare the future for younger generations, and wasted precious time and resources not addressing climate change and economic inequality which are oppressive for most in this scenario. Many older people, lacking affordable housing and tired of the contentiousness of age-diverse communities, have found comfort on the open road. Autonomous, Electric RVs (ARE-Vs) have opened the country to a new camper generation—people growing old in tiny-homes-on-wheels, remaining in constant motion, staying away from storms and heat waves in search of balmy weather and community. (*See supplementary material section 3 for Live Free & Die Free narrative*).

Key features of scenario 3

Pressures on society from climate change and demographic transitions have eroded social safety programs in the U.S., particularly those seeking to alleviate the ravages of time and poverty on older adults.

● Responsibility for life after retirement is almost entirely individualized, resulting in significant variability in financial conditions of older adults.

Older adults across the board, but especially those with less, join a growing movement in Gerotranscendence. Older adults in this

movement seek escape from the confines of physical age and social isolation, regardless of economic status.

● People have the opportunity to immerse in rich online environments where, using avatars, they can interact (sometimes even across generations) in environments ranging from highly realistic to wildly fantastical.
● Online communities of older people offer opportunities for social engagement, virtual community meetings, and political rallies.
● Despite opportunities for virtual escape from harsh realities, there is increased prevalence of suicide among the older poor.

Older adults of means live in age-segregated communities which offer innovations in life and healthspan extension.

● Communities are highly customizable with state-of-the- art dwelling and civic spaces.
● Communities are driven to be innovative, user-focused, and seek improvements in technology and care to benefit the healthspans of their residents, referred to as partners-in-residence.

Posh and innovative, age-segregated communities are economically out of reach for most.

● For older adults of middling means and long-term care needs, assisted living facilities are available but often with out-of-date technology.
● For older adults seeking alternatives to age-segregated communities, a new "camper" cohort roams the country in autonomous recreational vehicles (ARE-Vs) seeking shelter from climate change impacts; seeking meaningful connections to others; and finding freedom from highly curated technological environments often designed for people with youth, wealth, or both.

Digital environments often share information about surviving and thriving outside of high-wealth enclaves.

● Sub-cultures of DIY technologists and hackers often work to gain access to the greater services and functionalities high-wealth communities commonly restrict.

Health-related data are owned by private companies and, to a much-diminished degree, public organizations.

● Data generated by people living their lives amidst smart technology are used by companies to increase profit, not necessarily with regard for the wellbeing of broader user groups or the more general public.
● Age-segregated communities are living labs where residents' data are continually feeding a research apparatus focused on innovations in healthcare and life extension.
● People expect to have their activity monitored; DIY and hacker communities and the technologically literate may seek to circumvent or avoid monitoring.

Scenario 4: Final Nesting Place (Low technological choice + Low social integration)

Aging is a national obsession. Older Americans are staying in the workforce longer and are an economic and political force. Aging millennials and gen-Xers have put their voices toward advances in gero-science, the science of wellbeing, and the nationwide development of elder villages. With the elder village development program, aging people throughout the U.S. are able to age in their homes, with their neighbors, and with the assistance of smart technologies, VR check-ups and check-ins, and automated transportation. Lower-income Americans often age in their homes, many of which have been converted to elder apartment villages and share houses, or they move into state-run elder communities.

The culture of aging has shifted from prolonging life at all costs to developing systems that enable the extension of healthspans and the contraction of costly, life-extending care. Smart technologies are used throughout homes and in bodies, often mandated by the government or corporations in exchange for access to the best available medical care. The big data revolution has led to the development of predictive monitoring of people, families, and communities to anticipate ill health and offer—or mandate— behavioral, relational, or medical changes to improve health and wellbeing. Policy focused on the security of smart devices and the privacy of individuals has set a high bar for technology in the marketplace. As a result, the number of options available for smart technologies is limited and produced by large corporations capable of reliably meeting rigorous standards. However, the choices available to consumers, recommended by providers, or required by the government are of high quality. The transition to pervasive monitoring was wrought with unease, but in 2050 most people have become accustomed to the systems that pervade their homes, workplaces, communities, and even their bodies. People over 75 are often subject to restrictions on activities and choices, aimed at healthspan extension and improved wellbeing. These restrictions can cause tensions with loved ones and partners. While people always find ways to cheat these systems, broad adoption and implementation have lowered the cost and made quality healthcare available to most Americans. As a result, the average lifespan has increased to nearly 100 in the U.S. with lifespans among the poorest 1/3 of Americans averaging 90 years. (*See supplementary material section 4 for Final Nesting Place narrative*).

Key features

Lifespans and healthspans are significantly extended.

● People work longer into old age, with areas of activity changing over time as older adults phase into mandatory retirement.

Integrity, privacy, and security of healthcare technologies are required to be of high quality.

● Government ability to conduct large-scale, evidence- based, comparative research on aging has yielded breakthroughs.
● Although overall quality is greater and more people have access to these life-enhancing technologies, there are fewer options available for any single technology in the marketplace.

The focus of the healthcare system has shifted from prolonging life by any means necessary, to one of increasing an individual's healthspan and reducing the cost and extent of life-lengthening (but not quality-improving) care.

● Healthcare providers, patients, families, and new generations of experts engage in extensive end-of-life planning.
● Personalized medicine and health care impose increasing restrictions on individual activities and choices to support healthspan extension and wellbeing.

People tend to live with others in their age cohort, rather than across cohorts.

● Smart implants and devices on the person and in the home enable improved monitoring and care.
● Homes are alive with smart technologies that inform and direct the behavior of inhabitants for improved healthspans.
● Despite improved wellbeing, people experience a tension between better care and decreased control over health decisions.
● AR/VR enables virtual check-ins with care providers to further improve the wellbeing and healthspan of older adults.

Health-related data are largely viewed as a public good. Monitoring and health-data collection allow for the continuous personalization and improvement in care that people have grown accustomed to, and companies have grown accustomed to designing for.

● Individuals are scored and categorized based on a wellness quotient. This determines levels of smart interventions in one's home and on one's body.

There is less agency for individuals but also more freedom. For example, no one owns a car, but cars are widely available for transportation; it is simple to arrange and enjoy travel.

Discussion

In the discussion that follows we explore how the uncertainties affecting aging in smart environments of 2050 in the U.S. might play out, impacting lives of aging adults and implicating loved ones and society more broadly. Where appropriate, we put these findings into broader conversation with literature on futures of ageing and technology. We then discuss several possible limitations of the study before concluding.

Discussion of five provocations

Observing the plausible ways various provocations play out across the four scenarios affords an opportunity to dialogue with the future and invite reflection on present courses of action. Contrasting the multidimensionality of the four scenarios in this way throws into relief considerations governments, corporations, communities, and citizens might take to alter courses of the future of aging in rapidly developing smart environments. Altering such societal dimensions is essential in often technology-solution-driven conversations about futures of aging adults (Bechtold, Capari, & Gudowsky, 2017). We discuss below the four scenarios in the provocation contexts: dimensions of intergenerational relations; interpersonal and human-environment connections; information and sensing; potential need satisfaction; and policy and political driving forces.

How might intergenerational relations fare?

From the scenarios we see multiple fates of intergenerational relations. The trend toward multi-generational households exhibited in *Well Assisted* and *How Terribly Strange to be 90* reveals how the convergence of life-extending technologies and the exigencies of economic and climatic circumstances create intergenerational dependence of varying kinds. Multi-generational households in futures colored by these dimensions may consist of collections within families - parents, children, and grandparents – but also, alternatively, shared living among non-familial relations across generations. Technological literacy and digital socialization will also affect how people relate across generations. In *Live Free & Die Free and How Terribly Strange to be 90*, we see older adults of 2050 are technologically savvy in ways on par with younger peers, a phenomenon less common today. Older adults in these two scenarios are technology creators as well as consumers, using technology for their livelihoods in ways that bring them into regular contact, and sometimes conflict, with other generations. In *Live Free & Die Free* generational tensions exist not only across but also within age cohorts, as wealthy older adults retreat to age-segregated communities and invest their wealth in privatized health technologies for improved health and lifespans. Contrastingly, *Final Nesting Place* features more equitable intragenerational relations alongside intergenerational relations where appreciation of life experiences creates formalized, if stilted, conduits for knowledge exchange from

adults to youth. Centering the provocation around intergenerational relations allowed the scenarios to generate multi-dimensional solutions to social concerns. For example, as in other considerations of futures of aging and technology (c.f., Bechtold et al., 2017), isolation and loneliness surfaced as a prominent concern across the scenarios. Framing the problem as one of intergenerational relations afforded a perspective that speaks to issues of learning, livability, and economic viability.

How will people connect to one another and their environments?

Across the four scenarios presented, the texture of digital life varies greatly as it features ever more prominently in our bodies, homes, and environments. For older adults in 2050, smart technologies enable independence, mobility, and remote access to work, continued education, socialization, and recreation. While these expressions of connection vary across scenarios, the immersive digital environments they reveal, integrated with augmented physical environments, allow people to seamlessly move between virtual and physical realities as tasks and situations demand. *Live Free & Die Free* and *How Terribly Strange to be 90*, while starkly different in intergenerational relations, illuminate futures in which, when faced with stressful, unsatisfying, or lonely situations, older adults seek refuge in virtual spaces or filters to escape the physical world. In *How Terribly Strange to be 90, Final Nesting Place,* and *Well Assisted,* AI-enabled, assistive technologies have similarly liberated from the confines of singular devices to more fully occupy and augment the physical spaces where people interact. Digital assistants, for personal, healthcare, even sexual applications are embodied in ways that make them appear and feel present in physical space. Such seeming is augmented by fully realized and enabled AI-monitoring systems providing real-time data to and eliciting recommendations from friends, kin, and caretakers alike. Such technological connectivity is of course, not a given, and is tempered by the kinds of changes in social norms and policies explored in the provocations below. Needs for connection, affiliation, and inclusion are reflected as vital in other imaginings of smart cities and older adults (Gudowsky, Sotoudeh, Capari, & Wilfing, 2017). Indeed, these scenarios and the work of Gudowsky et al. (2017) illuminate that when considering inter-personal and environmental connectivity in futures for older adults, a human-centric approach—beyond gero-centric—may be better positioned to enable thriving across generations (c.f., also Bechtold et al., 2017).

What will we do with all the information gathered through sensing?

Views of publicness or privateness of sensed data—and thereby how such information is mined, leveraged, and directed toward benefiting people—played a strong role in coloring the futures explored in our scenarios. In *How Terribly Strange to Be 90*, we observe people empowered by individual data ownership, driving new markets for information exchange as well as healthcare technology and vibrant DIY and hacking cultures. Such DIY and hacking approaches feature prominently in *Live Free & Die Free* as well, yet are colored by a more oppositional stance to private ownership and exclusion from data environments. The way corporate-owned data pools deliver cutting-edge personalized technological benefits to the wealthy in *Live Free & Die Free* stands in stark contrast to what we see in *Well Assisted* and *Final Nesting Place*, where data are viewed as public goods. *Well Assisted* and *Final Nesting Place* each demonstrate how data sensing and collection in the public interest could lead to drastically improved health outcomes across age cohorts and income brackets. At the same time, the differences in these two scenarios showcase how benefits of publicness may be realized in different ways: in *Well Assisted*, leveraging intergenerational and community cohesion to drive savings and care improvements; in *Final Nesting Place*, opting for more centralized, segmented responses to determine life-enhancing technology and care distribution. Across all scenarios, the ability of governments, businesses, communities and individuals to make meaning from all of the sensed information proves paramount to benefiting from technology-enabled, personalized care regimes. By offering an overall frame of questions of publicness or privateness of sensed data, the scenarios add dimensionality to other considerations of ways in which deployment of ICT for heatlh and aging may be problematic (c.f., Flick et al., 2020).

How will innovations in smart technologies serve the needs of older adults?

In each of the four scenarios older adults stand to benefit from smart technologies embedded in bodies, homes, and surroundings. The scenarios envision innovative benefits related to extending health- and lifespans through AI-mediated precision medicine; application of sensing and information technologies to enable distance and on-demand care; and communication and multimedia applications like AR/VR to support life-long learning and counter social isolation. Still, as discussed above and below, the way data and other social policies develop will have major implications for whether and how such innovations pervade society and serve older adults. In *Well Assisted*, we observe how family relations and government incentives mediate choices in healthcare and technology as well as community responses to innovative climate change resilience measures. In *How Terribly Strange to be 90*, holographic, AR/VR and other technologies help extend healthspans as well as offer major outlets of individual expression and profession among older adults. Such expression is tempered, in *Live Free & Die Free,* by the access of affluent individuals to cutting-edge technology from private healthcare innovation hubs, and the reliance by everyone else on diffusion through either generosity, resale, or more subversive means. Electric, Autonomous-RVs enable a new generation of mobile, climate-responsive older adults in *Live Free & Die Free.* Older adults finding themselves in a world textured by features of *Final Nesting Place* may benefit from healthcare, communication, and monitoring innovations whether they like it or not. Across the scenarios, patterns of education, work, and retirement will further shape the degree to which older adults of the future are included in, supported by, or excluded from potential technological innovation. Exclusion of the voices of older, as well as younger, citizens—as distinct from other stakeholder or experts associated with aging and future technology—is a pitfall illuminated by Cozza et al. (2019), as is the importance of attending to blind spots in construction of the social group of older adults (e.g., omitting non WEIRD (Henrich et al., 2010) older adults or discounting gender heterogeneity).

How will policy and politics shape the social and technological landscape of the future?

Across the scenarios, the ways in which health- and lifespan extending technologies benefit older adults is heavily mediated by the

overarching social systems that incentivize care within communities and across individuals. In *Well Assisted* and *Final NestingPlace,* coherent policy responses employ data generated by advances in connectivity and sensing to mobilize system-wide cost-saving and care-improving interventions in peoples' lives and communities. By contrast, in *How Terribly Strange to Be 90* and *Live Free & Die Free,* more diffuse approaches to data ownership and high variability among abundant technology spark individualized responses and creativity. In these scenarios, we see starkly how wealth continues to heavily mediate affordances in wellbeing. Policies and programs across scenarios not only affect the care and technology people access, but how people might benefit by transitioning to multigenerational communities (*Well Assisted*), or instead leverage enhanced choice and technologies to realize greater mobility in response to extreme climatic change (*Live Free & Die Free*). Policies structuring who owns and benefits from data, as well as how surveilled information is leveraged to drive beneficial innovation also varies starkly across the scenarios. As Cozza et al. (2019) intimate, and these scenarios support, both a future ubiquity of technology as well as pervasive surveillance-heavy, market-oriented frames of such technologies warrant scrutiny where future public welfare is an animating goal.

Limitations

As a means helping people navigate complex futures under conditions of uncertainty, scenario studies are not without limitation. Scenarios start from the acknowledgment that the present exists and is experienced differently by different people; that the future will be similarly diversely experienced; and that the paths between our complex present and an uncertain future are many, contingent, and not always readily apparent (Wack, 1985; Ramírez & Selin, 2014; Keeler et al., 2019). The scenarios created are therefore constrained by our expertise and the expertise of those invited into the scenario creation process. Despite earnest efforts to cast a wide net for participants, including researchers from more than 10 disciplines as well as city practitioners and youth representatives, the absence of still more areas of expertise clarifies certain aspects lacking in the scenarios. For example, the absence of included energy and water infrastructure or civil or environmental engineering expertise speaks to gaps in the ability to envision and make more plausible the depth and complexity of material aspects of the futures explored. Such gaps may be related not only to missing experts, but also missing public voices. For example, Bechtold et al. (2017) observed that it was citizens, not stakeholders or even most experts, who expressed concern over sustainable resource use in visions of ambient assisted living in the City of Vienna, Austria. In addition to user groups, certain technologies prominent today, like hearing aids, already designed to counter hearing loss and social isolation among older adults (e.g., Malinoff & Weinstein, 1989; Dalton et al., 2003), were omitted and could have served as tangible touchstones for enriching detail. While such absences are notable, they also present invitations to further use the scenarios, not only with experts and stakeholders, but as Bechtold et al. (2017) bear out, with diverse publics. How might utilities operate differently in one scenario from another? How might various energy and water resource conditions alter the course of these futures or shape the social orders comprising them? How might the scenarios themselves vary (and with what strategic implications) if more explicitly generated with inclusion of non-WEIRD lay publics? These and other questions offer rich content to further promote the kind of constructive divergent thinking intended in the spirit of the scenarios as we employed them.

The scenarios were further limited by the reality of not being able to know the specific capabilities and nature of technology in 2050. Given the pace of innovation and the globalized nature of smart technology research and development, speculation about the specific technical features or functioning of smart technologies beyond the next 10 years is often futile. Nonetheless, speculation about social conditions and the potential role technologies could play in augmenting the lived experiences of older adults in the future serves a vital goal of developing futures consciousness (Ahvenharju, Minkkinen, & Lalot, 2018). The insights from anticipating developments at the intersections of people, technologies, our environments and mediating social circumstances do not require technical specificity, only creativity and suspension of disbelief (Guston, 2013). Rather than technological forecasting, we sought to illuminate plausible futures for aging in smart environments to afford greater discussion – in the present – about innovation trajectories, inclusion of older adults in innovation processes, and the role of social policy in shaping the distribution of risks and benefits from smart technology.

Conclusion

At their core, these scenarios aim to support dialogues to iteratively create futures, rather than rely on necessarily imperfect predictions of the future to unfold. We hope these scenarios contribute to discussions about possible critical decision points, areas to invest time and resources, new opportunities and potential pitfalls, vital relationships and connections, and aspects of the future that require further investigation, and aspects of the present that require further interrogation. What our scenarios make clear is that a new singular vision of retirement is unnecessary and perhaps undesirable. As the contemporary experience of many older adults attests, singularity of vision, like that of Del Webb's Sun City, begins to look more and more like a form of myopia, blinding many Americans to the harsh impacts of socio-economic inequalities on older adults and their loved ones. The smart environments of 2050 may offer connectivity, refuge, and access to virtual environments that are embodied, haptic, and integrated with the physical world. However, the scenarios reveal that for older adults in 2050 healthspans, life satisfaction, and sense of community are severely constrained by access to social programs and the capacity to navigate complex socio-technical landscapes to one's advantage.

We see from the four scenarios that smart environments and their benefits bend to the shape of society and not the other way around. The tensions revealed by the five provocations showcase how futures need not be uniform so long as dimensions of intergenerational integration; connectivity; making sense of sens-able information; need-oriented technology; and inequality are given due consideration. By imagining futures as diverse as the past and the present, we see that as inequality persists, it impinges, vice-like, on the possibilities of improved healthspans and lifespans for all Americans regardless of technological progress. The scenario approach used in this study offers one way to expose innovation to its social context, early in the innovation process, offering those who innovate

for aging people in the future an opportunity to see how their innovations might play out in nuanced, diverse, and often inequitable futures.

Acknowledgements

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.futures.2021. 102830.

References

Ahvenharju, S., Minkkinen, M., & Lalot, F. (2018). The five dimensions of futures consciousness. *Futures.* https://doi.org/10.1016/j.futures.2018.06.010.

Atzori, L., Iera, A., & Morabito, G. (2011). Making things socialize in the Internet—Does it help our lives?. December. In *Proceedings of ITU Kaleidoscope 2011: The Fully Networked Human?-Innovations for Future Networks and Services (K-2011)* (pp. 1–8).

Bechtold, U., Capari, L., & Gudowsky, N. (2017). Futures of ageing and technology – Comparing different actors' prospective views. *Journal of Responsible Innovation, 4* (May (2)), 157–176. https://doi.org/10.1080/23299460.2017.1360721.

Belsky, D. W., Caspi, A., Houts, R., Cohen, H. J., Corcoran, D. L., Danese, A., & Moffitt, T. E. (2015). Quantification of biological aging in young adults. *Proceedings of the National Academy of Sciences, 112*(July (30)), E4104–E4110. https://doi.org/10.1073/pnas.1506264112.

Brynjolfsson, E., Horton, J. J., Ozimek, A., Rock, D., Sharma, G., & TuYe, H.-Y. (2020). *COVID-19 and remote work: An early look at US data, NBER working paper No. 27344 June 2020 JEL No. I15,J21,L23,M15,M5.*

Chermack, T. J. (2011). *Scenario planning in organizations: How to create, use, and assess scenarios.* Berrett-Koehler Publishers.

Cook, D., & Das, S. K. (2004). *Smart environments: Technology, protocols, and applications* (Vol. 43). John Wiley & Sons.

Costa, D. L. (1998). The evolution of retirement. *The evolution of retirement: An American economic history, 1880-1990* (pp. 6–31). University of Chicago Press.

Cozza, M., Crevani, L., Hallin, A., & Schaeffer, J. (2019). Future ageing: Welfare technology practices for our future older selves. *Futures, 109*(May 1), 117–129. https://doi.org/10.1016/j.futures.2018.03.011.

Cubanski, J., Koma, W., Damico, A., & Neuman, T. (2018). *How many seniors live in poverty? Issu brief.* Available at: Kaiser Family Foundation https://www.kff.org/medicare/issue-brief/how-many-seniors-live-in-poverty/.

Dalton, D. S., Cruickshanks, K. J., Klein, B. E., Klein, R., Wiley, T. L., & Nondahl, D. M. (2003). The impact of hearing loss on quality of life in older adults. *Gerontologist, 43*(5), 661–668.

DesRoches, & Taylor. (2018). The promise of smart and resilient cities. *The Bridge, 48*(2).

Dhaka, P., & Johari, R. (2016). HCAB: HealthCare analysis and data archival using big data tool. *Information Processing (IICIP) 2016 1st India International Conference on*, 1–6.

Federal Ministry of Transport and Digital Infrastructure (FMTDI). (2017). *Ethics commission - automated and connected driving (Report extract). (June).* Retrieved from https://www.bmvi.de/SharedDocs/EN/Documents/G/ethic-commission-report.pdf?_blob=publicationFile.

Flick, C., Zamani, E. D., Stahl, B. C., & Brem, A. (2020). The future of ICT for health and ageing: Unveiling ethical and social issues through horizon scanning foresight. *Technological Forecasting and Social Change, 155*(June 1), 119995. https://doi.org/10.1016/j.techfore.2020.119995.

Fodor, G., Dahlman, E., Mildh, G., Parkvall, S., Reider, N., Miklós, G., & Turányi, Z. (2012). Design aspects of network assisted device-to-device communications. *IEEE Communications Magazine, 50*(3), 170–177.

Freedman, A., & Nicolle, J. (2020). Social isolation and loneliness: The new geriatric giants: Approach for primary care. *Canadian Family Physician, 66*(3), 176–182.

Friend, T. (2017). Silicon Valley's Quest to Live Forever: Can billions of dollars' worth of high-tech research succeed in making death optional? *New Yorker (New York, NY: 1925), 2017.* A Reporter at Large. April 3 Issue. available at: https://www.newyorker.com/magazine/2017/04/03/silicon-valleys-quest-to-live-forever.

Garden, H., & Winickoff, D. (2018). Gene editing for advanced therapies: Governance, policy and society. *OECD science, technology and industry working papers, No. 2018/12.* Paris: OECD Publishing. https://doi.org/10.1787/8d39d84e-en.

Gudowsky, N., Sotoudeh, M., Capari, L., & Wilfing, H. (2017). Transdisciplinary forward-looking agenda setting for age-friendly, human centered cities. *Futures, 90* (June 1), 16–30. https://doi.org/10.1016/j.futures.2017.05.005.

Guston, D. H. (2013). Daddy, can I have a puddle gator? Creativity, anticipation, and responsible innovation. In R. Owen, J. Bessant, & M. Heintz (Eds.), *Responsible innovation: Managing the responsible emergence of science and innovation in society.* London: John Wiley and Sons, Ltd.

Inayatullah, s. (2017). Teaching and learning in disruptive futures: Automation, universal basic income, and our jobless futures. *Knowledge Futures: Interdisciplinary Journal of Futures Studies, 1*(1), 00-00.

Keeler, L. W., & Bernstein, M. (2020). *The future of aging in smart environments: Scenarios of 2050.* Tempe, Arizona: Arizona State University School for the Future of Innovation in Society, Global Futures Laboratory, and The Global KAITEKI Center. https://doi.org/10.17605/OSF.IO/TJQXP. Workshop Report.

Keeler, L. W., Bernstein, M., & Selin, C. (2019). Intervening through futures for sustainable presents: Scenarios, sustainability, and responsible research and innovation. In A. Losch, & A. Grunwald (Eds.), *Socio-technical futures shaping the present. Empirical examples and analytical challenges in STS and technology assessment.* New York: Springer.

Khosla, R., Chu, M.-T., & Nguyen, K. (2013). Affective robot enabled capacity and quality improvement of nursing home aged care services in Australia. *Computer Software and Applications Conference Workshops (COMPSACW) 2013 IEEE 37th Annual*, 409–414.

Kumar, T. V. (2017). State of the art of e-democracy for smart cities. *E-democracy for smart cities* (pp. 1–47). Singapore: Springer.

Langensiepen, C., Lotfi, A., & Puteh, S. (2014). Activities recognition and worker profiling in the intelligent office environment using a fuzzy finite state machine. *Fuzzy Systems (FUZZ-IEEE) 2014 IEEE International Conference on*, 873–880.

Linstone, H. A., & Turoff, M. (Eds.). (1975). *The delphi method* (pp. 3–12). Reading, MA: Addison-Wesley.

Malinoff, R. L., & Weinstein, B. E. (1989). Measurement of hearing aid benefit in the elderly. *Ear and Hearing, 10*(6), 354–356.

Martin, P. P., & Martin, P. P. (2005). Social Security: A program and policy history. *Social Security Bulletin, 66*, 1.

McDonald, L. (2013). The evolution of retirement as systematic ageism. *Ageism and mistreatment of older workers* (pp. 69–90). Dordrecht: Springer.

Miller, J., McDaniel, T., & Bernstein, M. J. (2021). Aging in smart environments for independence. Forthcoming. *IEEE transactions of technology and society.*

Mitchell, C. (2021). *How telecom monopolies are blocking better internet access, and what we can do about it.* Available at: Institute for Local Self Reliance https://cdn.ilsr.org/wp-content/uploads/2021/01/SLPG_Broadband.pdf.

Morbidity and Mortality Weekly Report. (2003). Public health and aging: Trends in aging — United States and worldwide. *Centers for Disease Control and Prevention, 52*(06), 101–106. Atlanta, GA 3. February 14 Available at: https://www.cdc.gov/mmwr/preview/mmwrhtml/mm5206a2.htm.

National Academies of Sciences, Engineering, and Medicine. (2016). *Gene drives on the horizon: Advancing science, navigating uncertainty, and aligning research with public values.* Washington, DC: The National Academies Press. https://doi.org/10.17226/23405.

National Academies of Sciences, Engineering, and Medicine. (2018). *The promise of genome editing tools to advance environmental health research: Proceedings of a workshop—In brief.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25136.

National Research Council. (2012). *Aging and the macroeconomy: Long- term implications of an older population.* Washington, DC: The National Academies Press. https://doi.org/10.17226/13465.

Noble, D. F. (1978). Social choice in machine design: The case of automatically controlled machine tools, and a challenge for labor. *Politics & Society, 8*(3–4), 313–347. https://doi.org/10.1177/003232927800800302.

OECD. (2018). *Aging and employment policies: United States 2018: Working better with age and fighting unequal aging, aging and employment policies.* Paris: OECD Publishing. https://doi.org/10.1787/9789264190115-en.

OECD. (2017a). 3D printing and its environmental implications. *The next production revolution: Implications for governments and business.* Paris: OECD Publishing. https://doi.org/10.1787/9789264271036-9-en.

OECD. (2019a). *Working better with age, aging and employment policies.* Paris: OECD Publishing. https://doi.org/10.1787/c4d4f66a-en.

OECD. (2017b). Benefits and challenges of digitalizing production. *The next production revolution: Implications for governments and business.* Paris: OECD Publishing. https://doi.org/10.1787/9789264271036-6-en.

OECD. (2019b). The road to 5G networks: Experience to date and future developments. *OECD digital economy papers, No. 284.* Paris: OECD Publishing. https://doi.org/10.1787/2f880843-en.

OECD Science, Technology and Innovation Outlook. (2016). *What do companies use additive manufacturing technologies for? As a share of total use DOI.* https://doi.org/10.1787/sti_in_outlook-2016-graph7-en.

Ortman, J., Velkoff, V. A., & Hogan, H. (2014). *An aging nation: The older population in the United States population estimates and projections.* US Census Bureau. May 2014.

Palgi, Y., Shrira, A., Ring, L., Bodner, E., Avidor, S., Bergman, Y., & Hoffman, Y. (2020). The loneliness pandemic: Loneliness and other concomitants of depression, anxiety and their comorbidity during the COVID-19 outbreak. *Journal of Affective Disorders, 275*, 109–111. https://doi.org/10.1016/j.jad.2020.06.036.

Pew Charitable Trust. (2019). *Internet/Broadband fact sheet.* Accessed 1/31/2021 from https://www.pewresearch.org/internet/fact-sheet/internet-broadband/.

Poslad, S. (2011). *Ubiquitous computing: Smart devices, environments and interactions.* John Wiley & Sons.

Pournaras, E. (2020). Proof of witness presence: Blockchain consensus for augmented democracy in smart cities. *Journal of Parallel and Distributed Computing, 145*, 160–175.

Ramírez, R., & Selin, C. (2014). Plausibility and probability in scenario planning. *Foresight, 16*(1), 54–74. https://doi.org/10.1108/FS-08-2012-0061.

Rashidi, P., Cook, D. J., Holder, L. B., & Schmitter-Edgecombe, M. (2011). Discovering activities to recognize and track in a smart environment. *IEEE Transactions on Knowledge and Data Engineering, 23*(4), 527–539. https://doi.org/10.1109/TKDE.2010.148.

Reis, A., Paulino, D., Paredes, H., & Barroso, J. (2017). Using intelligent personal assistants to strengthen the elderlies' social bonds. In M. Antona, & C. Stephanidis (Eds.), *Universal access in human–computer interaction. Human and technological environments* (pp. 593–602). Cham: Springer International Publishing.

Sadowski, J., & Bendor, R. (2019). Selling smartness: Corporate narratives and the smart city as a sociotechnical imaginary. *Science, Technology & Human Values, 44*(3), 540–563.

Sáez-Martín, A., Haro-de-Rosario, A., & Caba-Perez, C. (2014). "A vision of social media in the Spanish smartest cities", Transforming Government: People. *Process and Policy, 8*(4), 521–544. https://doi.org/10.1108/TG-03-2014-0010.

Santini, Z. I., Jose, P. E., York Cornwell, E., Koyanagi, A., Nielsen, L., Hinrichsen, C., … Koushede, V. (2020). Social disconnectedness, perceived isolation, and symptoms of depression and anxiety among older Americans (NSHAP): A longitudinal mediation analysis. *The Lancet Public Health, 5*(1), e62–e70. https://doi.org/10.1016/S2468-2667(19)30230-0.

Selin, C., Kimbell, L., Ramirez, R., & Bhatti, Y. (2015). Scenarios and design: Scoping the dialogue space. *Futures, 74*, 4–17.

Trolander, J. A. (2011). *From Sun Cities to the villages: A history of active adult, age-restricted communities.* Gainesville: University Press of Florida.

UNDESA (United Nations Department of Economic and Social Affairs). (2017). *UNDESA (United Nations department of economic and social affairs).* Available at: https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html.

Wack, P. (1985). Scenarios: Uncharted waters ahead. *Harvard business review.* September 1985. Available at: https://hbr.org/1985/09/scenarios-uncharted-waters-ahead.

Wagner, L., & Luger, T. (2020). Age as an element of diversity: Intergenerational discussion to improve age-related attitudes. *Innovation in Aging, 4*(Suppl 1), 532.

Walters, D. (2011). Smart cities, smart places, smart democracy: Form-based codes, electronic governance and the role of place in making smart cities. *Intelligent Buildings International, 3*(3), 198–218.