# Smart Technologies and Internet of Things Designed for Aging in Place

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**Abstract.** One of the challenges accompanying the global rise in aging populations is the increase in demand for care services. With an increase in age, the need for medical support also grows, which may lead to unplanned and frequent visits to the doctor. Recent developments in Smart technologies and the Internet of Things (IoT) will play an important role in designing suitable home healthcare support services for older adults and enable self-care for people as they age at home. The current COVID-19 pandemic has accelerated the push for telehealth technology solutions including remote patient monitoring for senior adults who are medically or socially vulnerable. Remote health services are being promoted as a means of preserving the patient-healthcare provider relationship at times when an in-person visit is not practical or feasible, especially during COVID-19 and beyond. Smart technologies and IoT could potentially improve health outcomes and save lives. This paper will explore issues and challenges in introducing smart technologies and IoT into the homes of older adults, as well as explore features of the technology and potential outcomes that could allow older adults to remain autonomous, independent, safe, and encourage aging in place. The paper also identifies technology gaps and areas for future research.

**Keywords:** Smart technologies · IoT · Remote healthcare · Seniors · Pandemic

## 1 Introduction

Internet of Things (IoT) has a broad range of definitions and authors across the research literature use inconsistent terms to address the devices present in the IoT environment [47]. Two popular definitions of IoT are:


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"A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network" [30].

"Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental, and user contexts" [26].

The devices present in the IoT include mobile devices, smart devices, mobile technologies or mobile smart devices [47]. Interconnected objects play an active role in what might be called the "Future Internet" [26] with sensors as one of the key building blocks of IoT [4,33]. IoT technologies are also considered as enablers in future healthcare [33]. One of the challenges of an aging population is the increase in demand for care services [5,32]. As people age, their need for medical support grows, which may result in more frequent and unplanned visits to the doctor or trips to in-clinic healthcare services. Recent developments in smart technologies and IoT could play an important role in designing suitable home healthcare support services for older adults and enable self-care for people as they age [32]. There is a clear economic benefit in promoting aging in place, for example, for health policy makers in the 'aged care sector', assistive technologies to support older adults to age in place could provide less expensive (and preferable) alternatives to institutional care [10].

The current pandemic has created challenges for healthcare in both hospital and home care settings with an increased need for virtual care and online consultations for vulnerable populations. Seniors living alone, both in fair and poor health, are considered vulnerable and at-risk for health-related complications from COVID-19. Dr. Paul Hebert, Special Advisor tothe Canadian Red Cross [9] mentioned that "these are not new challenges for isolated older adults, especially those with chronic health concerns. The pandemic simply underscores them". The pandemic has also increased the proliferation of technological solutions for digital health, including IoT, wearables, and emerging smart home systems for daily living activities, health and wellness. Older adults are the primary users of technologies for aging in place and the main benefactors. However, the design and development of home healthcare technologies are often led by the requirements of social and caregiving environments, rather than by the needs and preferences of older adult users [12]. The mismatch between functionalities, intrinsic motivations and expected benefits can have a significant impact on technology acceptance [13] and can reduce the rate of technology adoption [10]. The next sections of the paper will explore research in the area of smart technologies and IoT, and the features and functionalities that could potentially enable older adults to remain autonomous, independent, safe, and to age in place at home.

## 2 Aging in Place with IoT and Health-Related Smart Home Technologies

IoT and health-related smart home technologies are being developed to meet the needs and requirements of a rapidly aging population. The literature identifies some challenges in the area of IoT and health-related smart home technologies for aging in place which will be examined in more detail in the next sections.

### 2.1 User Needs and Technology Requirements

Aging in place requires a more holistic view of user needs and requirements for autonomous and independent living at home [45] including: health, safety/security, peace of mind, independence, mobility, and social contact. Some smart technologies and IoT for monitoring and care have been found to target only certain aspects of older adult's requirements from a limited viewpoint (e.g., health monitoring, safety monitoring), without considering cognitive and sensory assistance. Requirements are not mutually exclusive, but often overlap instead. For example, it is possible for an application to offer improved mobility as well as reduce dependency on others, or provide independence and at the same time reinforce social interaction. Demiris [14] identified six categories of health-related smart home technologies that address needs and requirements that are important in supporting aging in place, including the following:

- Physiological monitoring: e.g., vital signals, temperature and blood pressure monitoring.
- Functional monitoring/Emergency detection and response: e.g., general activity level, gait and meal intake monitoring. Abnormal or critical situation is detected as emergency through the data collection.
- Safety monitoring and assistance: e.g., automated lighting, accident prevention, hazard detection, and warnings.
- Security monitoring and assistance: e.g., detecting intruders versus familiar people in one's social network, and reporting identified threats.
- Social interaction monitoring and assistance: e.g., facilitates social interaction by phone or video chat.
- Cognitive and sensory assistance: e.g., medication reminders, lost key locators, task reminders and water temperature indicator.

Smart living applications for older adults should be: (S)ensible, (M)odern, (A)daptable, (R)esponsive, and (T)angible in delivering value to users through careful design and HCI and human factors considerations [45]. IoT-based remote monitoring can help in the management of age-related diseases (both acute and chronic), impairments (e.g., visual, physical and speech), and decline (e.g., forgetfulness). Chronic conditions and diseases, if neglected, are major contributing factors in the decline of functioning and the ability to live independently, which leads to older adults being referred to nursing home facilities [5].

IoT technologies for 'Ambient Assisted Living' (AAL) include enhanced, intelligent ambient environments in the following areas of application: smart

**Table 1.** IoT and AAL for support key needs and motives for an aging population.

| Activities | Supportive IoT or Ambient assisted living (AAL) |
|---|---|
| Daily activities and social connectedness | - Home care systems with integrated natural speech interaction<br>- Robots or virtual assistants for socially isolated seniors<br>- Applications for smartphones or tablets that offer social networks for communication and social networking (e.g., with caregivers or other old adults) as well as a number of public services such as medical assistance, shopping assistance, and Meals on Wheels<br>- Reminders for daily activities (e.g., take medicine, diet and exercise reminders)<br>- Applications that encourage social interaction: video-based communication to support mediated connections with family and virtual participation in activities etc. |
| Safety and security | - Applications for fall detection, (e.g., wearable sensors, context-aware visual systems and cameras)<br>- Activity recognition/posture recognition using wearable sensors placed on the wrists, chest and ankle of the user for detecting unusual activities (e.g., decreased mobility, depression, etc.), personal emergency, and medication management systems<br>- Safety monitoring: analysis of data that detect environmental hazards (e.g., gas leakage, stove on). Safety assistance includes functions such as automated lights for reducing trips and falls<br>- Security monitoring: measurements that detect human threats such as intruder alarm systems and emergency response |
| Health monitoring | - Applications for managing chronic diseases, telehealth allowing remote interaction with the patient, and collecting continuous health records<br>- Physiological assessment including pulse/respiration rates, temperature, blood pressure, blood sugar level, bowel and bladder outputs, etc. glucose, medication compliance, weight, and bio-sensors to track activities of daily living and health status, remote health monitoring using wireless medical devices (e.g., oxygen level tester, breathing, and blood sugar measurements)<br>- Functional assessment: general activity level measurements, motion, gait identification, meal intake, etc.<br>- Nutrition monitoring: food-related monitoring, physical activity monitoring and daily caloric expenditure for weight monitoring (by wireless scales), monitoring consumed meals and water<br>- Cognitive monitoring: automatic reminders and other cognitive aids such as automated medication reminders, key locators, etc.; verbal task instruction technologies for appliances and sensor assisted technologies that help users with deficits such as sight, hearing, and touch |

homes and smart environments, AAL and agent-based pervasive computing and decision-making methods, and IoT sensing technologies (wireless sensor networks, smart sensors, gateways, etc.) [2,5,33]. Current IoT solutions for AAL technology, home automation, and telehealth services include a combination of tools and devices to support aging in place. A consideration of key needs and motives in supporting activities of daily living, safety and security, as well as home health monitoring is required. Table 1 presents IoT solutions for AAL and key activities that are support from the literature [2,5,33].

The desire for autonomy is a primary driving factor for home monitoring sensor adoption [49]. Studies of smart home monitoring technologies show that older adults are willing to trade privacy (by accepting a monitoring technology), for autonomy [45,49]. As the information captured by the sensor becomes more intrusive and the infringement on privacy increases, sensors are accepted if the loss in privacy is traded for autonomy [25,45,49]. Even video cameras, the most intrusive sensor type, are accepted in exchange for greater autonomy and an option to age at home [49].

Al-Shaqi [2] conducted an extensive literature review to identify current practices and directions for future research in AAL and found that most studies and system designs were based on the belief that the behavior of end-users is consistent from day to day, or has a general pattern. The provision of 'support' for older adults often did not take into account irregular patterns and 'changes in daily routines' [2]. Besides health monitoring, one important aspect often ignored in system designs is the need for entertainment in the lives of older adults, which is equally important for their well-being. Entertainment and leisure activities can have a significant impact on the quality of life, and part of the challenge is to identify requirements for an entertainment support system from the perspective of older adults and their caregivers alike [2]. A comprehensive review on the state-of-the-art of smart homes for elderly healthcare has identified several research challenges. Table 2 presents key areas of concern that must be addressed in order to encourage technology adoption in the context of aging in place [32].

### 2.2 IoT Standards: Technical Challenges

There are major technical challenges related to standards in IoT and AAL (one author describe IoT and AAL standards as 'almost unavailable' [2]. Some of the issues around standards include the lack of adaptability of different system components (i.e., sensors, communication protocols and decision support) [2]. Standards are often linked to the 'developer initiative' and are not well maintained [2]. Issues around system integration and interoperability of devices could interfere with the ability of technology to meet the needs and requirements of users [2]. Although IoT applications and services may increase the quality of peoples' lives, especially those with age-related disabilities or specific needs, the lack of accessibility standards creates a huge barrier [2]. Some of the accessibility requirements for IoT applications and services include: 1) Ability to perceive all information and capabilities of an IoT application or service, 2) Ability to understand the information presented by an IoT application or service, and 3) Ability to perform the required operations of an IoT application or service. Accessibility issues create significant barriers for users, caregivers, and healthcare providers alike [2].

**Table 2.** Recent advances and research challenges for smart homes for elderly healthcare and aging in place.

| Categories | Research challenges |
|---|---|
| Privacy and security | - Identified as the most pressing concern for smart home technologies. Privacy and security of the transmitted health data; data that may contain sensitive, protected or confidential information that can endanger residents' privacy and safety, if breached. Educating older adults (and caregivers) in areas of privacy and security related to home health monitoring and digital health technologies is a priority |
| Performance: efficiency, optimization and cost | - There is a need to develop more robust and efficient algorithms for healthcare systems (and devices) along with effective data compression techniques<br>- Portable and wearable physiological parameter measurement systems aimed at long-term monitoring need to be energy efficient. Energy harvesting techniques are being explored to fulfill the energy requirements of the devices<br>- Current efforts to increase efficiency will drive down cost<br>- Optimizing the performance of the smart home system for elderly healthcare will have an impact on cost which is a major factor in technology adoption (older adults are often on a fixed income) |
| Connecting complex systems and many discrete devices in one common platform | - Systems need to be designed to deal with integration issues among different devices, with an optimum number of sensors in order to avoid redundant data; infrastructure demands, maintenance cost, and energy consumption are key factors driving adoption<br>- Reducing energy consumption and cost will impact technology adoption |
| Modularity, acceptance and adoption | - Modular, extensible structures, expanded capability and interoperability of systems and devices among different smart home platforms are vital for achieving flexibility and widespread adoption<br>- Providing users with options to choose components from different manufacturers, or add (and remove) services will have an impact on cost and adoption rates |

Standardization is key to providing needed functionality, interoperability, and security for smart home technologies. The IEEE Standards Association (IEEE-SA) has been working in a number of areas to help build consensus on the adoption of wearable devices, including standards that enable the communication between medical, healthcare and wellness devices, and with external computer systems (IEEE-P1912) [19]. This standard specifies approaches for end-user security through device discovery/recognition, simplification of user authentication, tracking (items/people) under user control/responsibility, as well as supporting alerts; privacy is maintained through user controlled sharing of information that is independent of the underlying wireless networking technology used by the devices [19]. Other standards address networking and communication layers that provide low-cost, low-speed ubiquitous communication between devices, including international standards for low power, short range, and extremely reliable wireless communication within the surrounding area (including wearables), and support a wide range of data rates (low-data-rate transmissions, energy-efficient wireless technology) for different applications [19].

## 3 Models to Inform IoT and Smart Technology Adoption

Various models have been applied in studies of technology adoption, specifically in the acceptance of technology by older adults. The next section will explore these models as well as important predictors for smart home healthcare technology adoption by older adults.

### 3.1 Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT)

The Technology Acceptance Model (TAM) has been widely used in a variety of contexts to understand an individual's intention to use a technology, including technology acceptance by older adults [31,36,44], and technology acceptance in the context of aging in place [40]. More recently, TAM has been applied to research on acceptance of IoT-based gerontechnology by older users [33]. The Unified Theory of Acceptance and Use of Technology (UTAUT) has been applied in studies looking at the intent to use technology in healthcare [39]. The key variables influencing the behavioral intent to use technology are Perceived Usefulness (PU) and Perceived Ease Of Use (PEOU) [40]. Older adults have been described as the main target population for IoT and healthcare solutions, however, they are also considered to be conservative users. This poses a serious challenge to the successful implementation of smart home healthcare systems and services [39]. Eight significant predictors related to acceptance behavior for smart home healthcare technologies were identified based on an online survey with 254 older adults aged 55 years and older [39]. Important predictors included:

– Performance Expectancy: *(user perceptions related to the degree to which using a technology will provide direct benefits in performing certain activities*) this was the most significant predictor of smart homes for healthcare acceptance among older adults.
– Effort Expectancy: *(the degree of ease associated with the use of any system)* this was also an important predictor of smart homes for healthcare acceptance among older adults.
– Expert Advice: *(the degree to which users rely on external experts' opinion like doctors, nurses, or pharmacists in taking decisions related to their health; if the experts' feel and believe that using smart home for healthcare will be*

*beneficial)* this factor also played a role (but was not significant) as a predictor of smart homes for healthcare acceptance among older adults. Perceived Trust: *(the feeling that their personal data will be safe, carefully protected, and anonymous)* was also a predictor (but was not significant) of smart homes for healthcare acceptance among older adults.

– Social influence: *(which includes the opinions or suggestions provided by a home care nurse, friends and/or relatives).* Other *facilitating conditions* included the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the system. *Technology anxiety* and *perceived cost* were also important predictors (although not significant) to consider in smart homes for healthcare acceptance among older adult.

TAM studies on the 'behavioral intention' to use technology have focused on attitudes and perceptions at the pre-implementation stage (i.e., survey responses to hypothetical scenarios for technology solutions that may not exist yet) and may have overlooked other important factors. A study of community-dwelling older adults found that coping strategies can also have an impact on perceptions and attitudes around technology acceptance [40]. For example, in a study of technology acceptance for aging in place, community-dwelling older adults reported not feeling the need for supportive technology [40]. Community-dwelling older adults in this study were found to employ coping strategies for dealing with decline, including *'trying to keep one's' mind from focusing on oneself and one's own vulnerability'* and *'focusing on the present'* [40].

IoT and smart home healthcare support and services are still evolving, therefore technology acceptance studies (e.g., TAM and UTAUT studies) should include comparative investigations for different demographics (i.e., age, gender, culture) for a better understanding of the differences in consumer resistance to IoT-based smart homes [39]. In addition, opinions from older adults who actually live in smart homes should be considered, as it will represent a more realistic scenario in taking into account the 'different types of resistance' to technology adoption. The identification of factors which contribute to passive, active, and very active resistance to smart homes and IoT warrants further investigation, especially from the perspective of older users [39]. For example, older adults might perceive current smart home technologies and IoT services to be immature and in an early developmental stage, and they may not trust technology to be mature enough to be useful for them. Further empirical studies from the perspective of HCI and human factors are required in this area.

### 3.2 Human/Activity/Space/Technology Model (HAST)

HAST is an established environmental gerontological theory that looks at relationships between smart home technologies, physical (built) environment and caregiving in the homes of older adults who are aging in place [10]. HAST considers the factors and risks specific to aging in place that have an impact on older adults' health and well-being, along with outcomes following the implementation of IoT-based smart home technologies [10]. The socio-technical context is also considered in the role IoT-based smart home technologies can play in aging in place, beyond technological and engineering problems; engaging the engineering community, scientists, policy makers and end-users in addressing risks and concerns should lead to a more significant social and technological impact [10]. For example, HAST uses a case study approach which has been applied to investigate how IoT-based smart home technologies can interact with the caregiving environment in the home, with the following considerations:

– Personal profile: includes the persons' situational/health/functional needs, along with current formal and informal care needs.
– Care profile: documents the care needs (formal and informal) prior to the technology being introduced.
– Functional limitations: examines the implications of a person's health status on their ability to be independent at home.
– Physical (built) environment: includes modifications received in the home, listing barriers the person has faced in their home environment that may be preventing them from undertaking tasks independently, along with descriptive information about the environments.
– Smart Home technology: introduces the technology into the picture and explains which activities in the home are supported, the context of use (who instigated it, for how long, and whether it has been successfully used); with a technology analysis limited to smart home technologies (devices for managing tasks in the home environment, not health technology devices).
  The outcome of the HAST case study process results in a synthesis of collected data that documents the impact of the technology in terms of caregiving, health and well-being of the older person, as well as the impact on any caregivers. Limitations of the technology as experienced by the older person and family are also documented, and whether expectations and benefits of the technology have been met. Broader implications raised in case study approaches around the relationships between technology, physical (built) environments, care, health, and well-being warrant further research and discussion.

Despite technological advances in IoT-based smart homes, their adoption is still very low mainly due to their disruptive nature [39] and the inherent conservative nature of older adults in adopting any new technology [16,48]. Older adults are described as having a different mindset compared to early adopters of new technology [39]. For example, for older adults, privacy and security concerns with health data that the smart homes can collect, and costs are important factors that influence technology acceptance or resistance; this includes IoT-based smart home solutions for healthcare management and for aging in place [39,40]. It has also been suggested that to improve adoption, technical support and advice in real time could be provided by data centers and dedicated hotline numbers to assist older adults with customized help when needed [39], however, privacy and confidentiality laws around health data impose serious restrictions on the level of customized assistance available. Issues of privacy and security of smart home technologies and IoT will be examined in more detail in a subsequent section.

Other inhibiting factors may also have an impact on older adults' adoption of smart home technologies and IoT for aging in place, including an older person's unwillingness to learn new technology, lack of confidence with technology or the inability to maintain the technology [10]. An older adult may also dislike new smart home technology due to frustration, or fear of not being able to afford to continue to maintain or replace the technology [10]. Technical problems (e.g., power outages affecting connectivity of smart devices) and lack of proper training in the use of smart home technology could also affect technology adoption [10].

## 4 Designing Smart Technology and IoT for Aging in Place

Research in the field of IoT development and evaluation has recognized a number of challenges and limitations associated with past smart technology developments to support aging in place, calling for user centeredness and better integration with broader systems [3,10,39]. The factors that contribute to low technology adoption are complex and multifaceted, and are not limited to a person's chronological age or health status [10]. Poor interface design, issues of privacy and trust [54], as well as economic and educational barriers [51] also contribute to low rates of technology adoption by older adults. A number of studies have suggested that future IoT development will require a more user-centered and co-creative design approach [5,20,21,24,53] and age appropriate designs [41]. In addition to these considerations, more studies of IoT systems in the homes of older adults, in actual contexts of use, are required [40,43].

The lack of adaptable designs for people with impairments has also been identified as a barrier to smart living and its application for aging in place, specifically in the use of wireless devices [45]. Research and development efforts are required in the area of mobility-based smart devices for the older adults, to deliver localized, context-dependent, and user adaptable designs that consider user characteristics and conditions, as well as emotional or affective aspects such as feel, value, sensitivity, and appeal [46]. The design of smart technologies and IoT should be human-centric and encourage older adults to be more self-reliant, enhance their self-efficacy, and confidence to live on their own with personal freedom and individuality, and provide support for practical necessities, but also be aesthetically pleasing [46]. Aesthetics is an important design consideration for older adults, along with safeguards that protect personal information and information about activities of daily living. These are necessary design considerations in autonomous living with smart home interfaces that need human-centric design to minimize their stress [46]. Continuous research efforts and formal usability studies are required for IoT-based smart homes and intelligent ambient environments, to achieve greater customization, automation, and more contextually-sensitive and responsive systems and devices, which require more efficient interfaces [46]. Ease of use, degree of satisfaction, and reduction of error rates by older users in operating interfaces and devices are areas requiring more empirical studies [46]. Identifying key attributes to measure satisfaction levels of older users and the types of errors made while operating interfaces should feed into improved designs, with HCI and human factors considerations to support better customization and optimization of IoT-based smart living environments for older adults [46].

## 5 IoT, Privacy and Security, Acceptance and Adoption

The issue of data privacy and overall trust in smart home services for healthcare is an important factor that needs further exploration. Key privacy threat factors should be identified with better threat/risk models that will enable the various smart home stakeholders to create better strategies and policies which can assure a greater success of their services. Moderating effects of gender and cultural background should also be investigated further.

The research literature points to a serious lack of a theoretical/conceptual approaches in user acceptance modelling as the current focus is on the underlying technologies and services, rather than on the end-user [40]. In addition to the technological aspects related to trust, privacy and security, educating the end-users on these issues is also important [17]. A good example of the multitude of issues related to privacy, security and trust are the concerns with the use of wearables by older adults.

User acceptance is critical for the technology to be integrated within daily living, especially in areas such as IoT and wearables. A wearable technology is used to collect and deliver information about health and fitness related activities. Wearable devices (e.g., smartwatch, smart ring, smart band, smart clothing, etc.) are used widely by the general population to track exercise and health [42]. Originally designed to support medical needs, some modern consumer wearables have sensors that monitor and record sensitive patient health information (such as heart rate, respiratory rate, oxygen saturation, blood pressure, temperature, ECG, etc.), and also record physical activity (e.g., steps taken, distance travelled, sleep patterns, exercise activity, falls, etc.) [42]. Despite the widespread proliferation of wearables, there are many privacy issues and risks associated with consumer wearables that have yet to be resolved by industry and lawmakers [6].

Researchers have identified a number of privacy risks for consumer wearables including user context privacy, bystander privacy during data collection, external data sharing privacy, with proposed technology solutions to mitigate the risks [6]. Along with privacy by design technology solutions for IoT and wearables, privacy laws and regulations need to provide clear notice and mechanism for consent to inform users on the nature of possible privacy and security issues related to the intended use. It has been noticed that wearable systems perceived as intrusive can impact user acceptance – a fact that many technology developers overlook [2]. Additionally, applications of technological wearable solutions frequently suffer from a socio-cultural misunderstanding of group differences, and, as a consequence, lead to poor acceptance of technology by older adults, caregivers, and clinicians [2,50].

While the research literature points to various barriers such as the concern for privacy, followed by lack of trust when adopting technologies for use by older adults [40], it has been observed that there is also a willingness to give up some privacy for the benefit of staying in ones home [27]. Older adults view personal data protection as one of several important dimensions of privacy concerning home healthcare technologies, and they also have other privacy concerns related to aspects of personal privacy, such as intrusiveness and a feeling of surveillance which also have an impact on technology acceptance [35,50]. To address privacy considerations and improve technology adoption, researchers emphasize that technology developers should include older adults in the design process, and gather privacy requirements for such technologies [34,54]. Privacy concerns should be considered when designing health technologies for in-home use, and include not only the privacy of personal user data; all levels of users should be consulted, including the end-user (older adults), secondary users (caregivers) and tertiary users (clinicians) [34]. An overarching theme that warrants further research exploration is the trade-off between privacy (data and information privacy), the sense of surveillance and the invasion of personal space, and the freedom of safely living independently at home [35,44]. Additionally, the end-user perspectives and the need for autonomy and control must be balanced with privacy, security and trust in systems and devices [44], including smart home technologies and IoT.

### 5.1 Technology Acceptance Interviews

We recently conducted an exploratory study with older adults that was focused on technology acceptance in the context of home health monitoring and telehealth management, and "lived experience" during the pandemic [29]. The study participants previously received a tablet and a smartwatch as part of the pilot study on home health monitoring and telehealth management in the province of New Brunswick (Canada) in 2019. After 6+ months of the pilot study, we have conducted interviews with older adults who chose to continue the study. The sample of older adults (N = 6, ages 66 to 92) included both females and males, all college or University educated, some with active lifestyles and no medical conditions, while others had medical conditions which required home health monitoring. All participants (but one) used computing devices on a regular basis, for work or leisure, with some owning several mobile devices and smartwatches. The major areas of concern and "lived experience" for this sample of knowledgeable older adults included:

- Issues with privacy: The use of virtual assistants in the home (e.g., Google Home), "Google picks up on private conversations", "total invasion of privacy", "Virtual Assistant picked up on words in our conversations and started recommending things based on words it has picked up", "suddenly my computer will start displaying ads and numbers for pizza". "That's the only drawback, it's like big brother is watching", when we're having a private chat, I unplug it." "I am concerned with privacy and security with the tablet for home health monitoring. I don't want to share my data". Another senior was a victim of a fraud so now "we (family) will only use the tablet for information coming one-way to us—and that's all we are going to allow."

- Security versus surveillance (fall detection): One older adult expressed a concern that if it's "For seniors being in their own home—if it means being hooked up to something for when I fall and can't get up, well ok, I'm good with that" but intrusiveness and surveillance were an issue, "I think having a camera would bother me".
- Technical issues: Some older adults reported "stress and aggregation of setting up the tablet" (for home health monitoring), "the tablet didn't synchronize with the watch very well" and there were several bugs, "it took them one year to work out all the bugs". There were also issues with technology reliability and stability, "every 3 or 4 months the system will go down", "had to reboot after a power outage, Bluetooth went out", and the older adult had "no idea how to turn it back on to get it working again"; getting immediate technical support was an issue. Some older adults expressed frustration in "not having control of the devices", from the software end of it, "no manual", and not being able to do something as simple as "resetting the time on my smartwatch".

Some older adults also reported experiencing "fear, anxiety and stress" during the ongoing pandemic and had not seen their physician since the beginning of the pandemic (e.g., routine follow ups and blood work for chronic conditions were not completed). They would "welcome virtual care" but were "not aware if their physician offered virtual care services".

Findings from our exploratory study of "lived experiences" during the ongoing pandemic demonstrate a profound need for more social and home technology support for vulnerable older adults. Care technologies in the home environment require different contextual considerations, where privacy issues are key. From a data privacy perspective, devices operating in the home are more exposed to unauthorized access than those in more controlled environments, such as nursing homes and hospitals [23]. Additionally, devices in the home also invade the personal space of the user, and their friends and family.

### 5.2 Privacy by Design, Usable Security for Home Healthcare Systems

Researchers have pointed out the potential benefits of smart technologies and IoT in providing home healthcare support to help older adults to age in place [10,40,52]. However, due to their novelty, complexity, and collection of vast amounts of sensitive personal health information, these technologies also pose serious privacy and security concerns for older adults. Further research is required to better understand the privacy and security attitudes and concerns of older users with respect to new emerging healthcare technologies in order to design usable and privacy preserving technologies [18]. Frik [18] has proposed a process for a usable security design which includes: a) capturing the privacy and security attitudes of older adults, b) building threat models, with surveys to empirically validate these models, c) participatory design sessions with older adults from the onset of the design process, to requirement gathering, model testing, and further threat model refinement, and d) making recommendations with regards to mitigation and control strategies. Better threat models and more usable security models are also required to empower older adults in the adoption and use of smart technologies and IoT for healthcare and for aging in place [1,18,40].

The importance of including older adults in co-design and in gathering privacy requirements for new emerging technologies for independent living has been emphasized in the research [2,54]. An overarching theme that warrants further exploration is the trade-off between privacy (data and information privacy), the sense of surveillance and the invasion of personal space, and the freedom of safely living independently at home [35,44]. User perspectives and the need for autonomy and control must be balanced with privacy, security and trust in systems and devices [44].

Smart technologies and IoT for home healthcare need to be built with cybersecurity in mind; with a consideration of user attitudes and perceptions around privacy and security in order to ensure successful use [15]. Research has shown that older adults are very aware of privacy issues [2,34] in the context of Ambient Assisted Living (AAL). Privacy seems to be more of an issue for technologies designed for aging in place, especially as older adults with health issues must learn to manage their personal health data [28]. Frequently, older adults are faced with challenges when navigating alone the complex relationship between loss of privacy and increased freedom for users and caregivers to collect data, as well as opening up the home environment to calls, checks, and home health monitoring [34,44,50].

Building usable security for older adults requires building privacy by design into the system [11] to improve security, and empower older adults to make informed decisions so that they have better control over their personal data. Further investigation is needed around privacy and security factors for various types of devices, types of data and how data is collected, choice of data recipients and context of use; how these factors affect older adults' privacy and security perceptions of emerging healthcare technologies, and, subsequently, widespread technology adoption, has yet to be explored in depth [18].

There is the potential for systems and devices to collect massive amounts of data and conduct non-stop surveillance which triggers privacy and security concerns among older adults, especially with respect to wearable devices, video recording and financial data, and a need to address inaccurate beliefs about the security of the technological systems in use [8]. Misconceptions about actual data collection and storage may cause security risks to be underestimated, and therefore lead to bad decisions regarding levels of protection for the user [8]. However, the World Health Organization (WHO) [38] argues that misconceptions about what data the system collects may raise false concerns that can be addressed when appropriate explanations are provided to the user.

Research has suggested that, in addition to the types of data collected, the recipients of data matter to older adults, i.e. it is important to know who accesses their data and how often, and to what level of detail [7]. A related concern is associated with the lack of feedback from the monitoring system about when it is in the recording mode. Older adults often rely on family members for support in "dealing with technology" [7]. Delegation of security (i.e., sharing login credentials with family members and caregivers) and issues with creating, remembering and entering passwords point to problematic security behaviors among older adults [7] and demonstrate that older adults' mental models of security and privacy may differ from those of younger populations [22]. All together, these findings underscore the complexity and diversity of privacy and security issues among older adults as a diverse group, and the need for further research [22].

## 6 Conclusion

One of the limitations in studies of smart technologies and IoT to support aging in place is that these services are relatively new and currently not available on a commercial scale. Therefore, the wide-scale introduction of services and technologies should be preceded by widespread technology usability studies, and followed up with further investigations into the actual technology acceptance as the step following the 'behavioral intention' to use. The issue of data privacy and overall trust in smart home healthcare services is an important factor that influences technology adoption by older adults. More detailed and careful analysis, with more threat factors identified and, subsequently, a threat/risk model created that will enable the various smart home stakeholders to create better strategies and policies will assure greater success of the services.

The moderating effects of age, gender, and cultural background on IoT and smart home technology acceptance have not been addressed sufficiently, and future studies should include a wider sampling of older adult users in various contexts of use, with co-design as a key factor in empowering older adults to take ownership of the health and well-being, and possibly influence technology adoption for aging in place as well. Future advances in research and development in these areas are anticipated under the National Research Council Canada, Aging in Place Program [37].

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