

STANDARDS RESEARCH

Guidelines for Smart Home Retrofits and New Builds for Aging at Home

November 2024

Authors

Gaya Bin Noon, B.Sc., University of Waterloo

Shahabeddin Abhari, B.Sc., M.Sc., MBA., MPH., Ph.D., University of Waterloo

Gillian Morgan, B.A., MHE, University of Waterloo

Ruah Al-Saghier, B.Sc., M.Sc., University of Waterloo

Dmytro Chumachenko, B.Sc., M.Sc., Ph.D., University of Waterloo

Plinio Pelegrini Morita, P.Eng., M.Sc., Ph.D., University of Waterloo

Project Advisory Panel

Langdon Baker, Smith + Anderson

Ted Maulucci, SmartONE

Ben Mortenson, University of British Columbia

Fiona Manning, CSA Group

Disclaimer

This work has been produced by the author and is owned by Canadian Standards Association. It is designed to provide general information in regard to the subject matter covered. The views expressed in this publication are those of the author and interviewees. The author and Canadian Standards Association are not responsible for any loss or damage which might occur as a result of your reliance or use of the content in this publication.

Table of Contents

Executive Summary 6

1 Introduction 7

1.1 Background and Motivation 7

1.2 Research Aims and Objectives 9

2 Existing Guidelines on Smart Living Environment Design 10

2.1 Codes and Standards 10

2.2 Best Practices from Research 11

3 A Sample Smart Home 12

3.1 Overall Infrastructure 14

3.2 Bedroom 15

3.3 Bathroom 15

3.4 Laundry Room 15

3.5 Living Room 16

3.6 Kitchen and Dining Room 16

4 Technology Evaluation 16

4.1 Types of Smart Home Technologies 17

4.2 Building Requirements 18

4.2.1 Physical Building Requirements 18

4.2.2 Electrical Building Requirements 19

4.2.3 Connectivity 20

4.3 Key Trends in AAL Technology 22

4.3.1 Lifestyle Monitoring, AI, and Predictive Models 22

4.3.2 Integration and Interoperability 23

4.3.3 Centralized Data Strategies 23

4.3.4 Circle of Care Integration 24

5 Recommendations for Smart Home Development 24
- 5.1 General Guidance 24
- 5.2 Retrofits 25
- 5.3 New Builds 26

6 Future Research Directions 28

7 Conclusions 29

References 31

Appendix A: List of Technologies 37

Appendix B: Technology Evaluation 51

Glossary of terms

Term	Definition
Active Assisted Living (AAL)	Systems designed with the goal of improving quality of life, aiding in independence, and creating healthier lifestyles. Also referred to as "ambient assisted living."
Adaptive technologies	Objects or systems specifically designed to adapt or modify existing technologies to increase or maintain the accessibility of devices for persons with additional accessibility needs.
Assistive technologies	Any product, software, or equipment purchased commercially, modified, or customized to maintain or improve the functional capabilities of people with disabilities.
Internet of things (IoT)	Interconnection of common, often household items through the Internet via embedded computing components.
Long-term care (LTC)	Facilities that offer a high level of continuous supervised care for individuals who have complex care needs and can no longer take care of themselves independently.

Executive Summary

Active Assisted Living (AAL) systems and devices have the potential to support Canada's aging population, enabling older adults to live independently for longer. Given the wide range of accessible, adaptive, and smart home technologies available to consumers, it is necessary to understand the building and infrastructural requirements of these technologies when used within a home-like environment. This understanding is crucial not only to address the evolving care needs of older adults but also to proactively anticipate these needs and create supportive living environments. However, there has historically been a lack of oversight guiding the development and implementation of AAL-enabled smart living environments, which has put the onus on manufacturers to shape the space.

The primary objective of this report is to explore requirements to facilitate the integration of AAL technologies in retirement and independent living settings. These guidelines will provide support for community developers, AAL technology manufacturers, builders, and construction companies engaged in retrofitting existing units and new building construction. Further, this report provides suggestions for best practice for the use of AAL technology, a nd considers the needs and characteristics of the infrastructure and ways to ensure that the built environment is resilient and capable of multiple iterations of AAL technology.

To achieve this objective, we examined guidance in existing building codes and standards, as well as published academic literature. A sample smart home use case was then developed to explore the practical considerations involved in smart home design for an older adult living in a retirement community, considering the home and community as an entire system. Lastly, an evaluation of 156 unique technologies from 143 vendors was done to determine the requirements for setting up a smart home, followed by an examination of upcoming trends in the space.

Based on these findings, general recommendations are presented, as well as additional considerations for pre-existing homes to be retrofitted into smart living environments and for newly built smart homes. General recommendations include taking care to avoid clutter; maintaining field of view; establishing data-sharing pathways; considering interoperability, security, and privacy protections of device options; and establishing plans to periodically re-examine and modify the smart home design. Key considerations for retrofits include addressing incompatibility between smart technologies on the market and the existing building infrastructure, minimizing disruptions to residents' lives, and ensuring the living environment remains familiar and comfortable throughout the transformation. For new builds, essential considerations include designing for modifiability as residents' needs and the state of technology changes, establishing backup systems for power and Internet, allowing for serviceability, and assessing whether a home has adequate network access to support the integration and functionality of the smart devices and systems. Finally, this report outlines recommendations for future research to further advance and refine the integration of AAL technologies in smart living environments to ensure continuous enhancement and effectiveness.



"Across the continuum of care, Active Assistive Living, IoT, and smart technologies can be used to help older adults maintain and improve their independence as they age and to avoid premature transitions to or between care settings."

1 Introduction

1.1 Background and Motivation

As life expectancy increases, it is expected that older adults will experience more complex and diverse care needs as they age, which in turn contributes to a growing need to help adults live independently for longer [1], [2]. The level and intensity of care required can evolve over the course of older adulthood, with a likely increase in needs over time. At each level of need, health care services and living arrangements are available to support health and well-being, albeit to different extents across different Canadian jurisdictions [3]. This continuum of care offers a range of options, from private home care to assisted living and retirement communities, to long-term care (LTC) [3].

Internet of Things (IoT) refers to the interconnectedness of independent web-enabled smart devices that can collect, share, and receive data without human intervention [4]. **IoT technologies** contribute significantly to creating innovative services and applications that can address the health care needs of older adults [5]. Specifically, IoT technologies designed for adaptive and assistive activities of daily living encompass a broad range of technologies that are integrated into a living environment, which can be used to support older people in living at home for longer while maintaining as much independence as possible [2]. Here, assistive technology describes any product, software, or equipment that can be purchased commercially, modified, or customized to maintain or improve the functional capabilities of people with disabilities [6], [9]. However, these devices are not exclusively designed for people with disabilities and are also commonly used by individuals to support various sensory, physical, and/or cognitive abilities such as hearing, vision, mobility, walking, memory, dexterity, and learning. Assistive technologies can include automatic door openers, remote-controlled appliances, voice activation, and reminder systems [7]. **Adaptive technologies,** a subset of assistive technologies, are objects or systems specifically designed to modify existing infrastructure or technologies to enhance or maintain device accessibility for persons with additional accessibility needs [6], [9]. For example, homes equipped with ramps, stair railings, and automatic lighting have adapted typical home infrastructure to enhance the accessibility and usability of an older adult's home environment.

Across the continuum of care, **Active Assistive Living (AAL),** IoT, and smart technologies can be used to help older adults maintain and improve their independence as they age and to avoid premature transitions to or between care settings [8]. AAL systems—typically comprising IoT devices—designed with the goal of improving quality of life, aiding in independence, and creating healthier lifestyles [9], are of particular interest within older adult care. With the breadth of accessible, adaptive, and smart home technologies available to consumers, there is an opportunity to help address older adults' evolving care needs, as well as potentially anticipating those needs and creating supportive living

environments. That said, many of these technologies can only be integrated once certain building and infrastructure requirements have been met [4], [5], [6], [7].

Better integration of smart home and IoT technologies in home living environments is a step toward the development of smart continuing care and retirement communities. Unlike LTC facilities, which provide constant, continuous supervised care for individuals who have complex care needs and can no longer care for themselves independently, retirement communities are flexible residential living environments designed for older adults to live either fully independently or with minimal care [10]. In 2018–19, the Canadian Institute for Health Information reported that approximately one in nine new Canadian LTC residents potentially could have received care in their own home [11]. Despite a growing desire among many older adults to remain at home for as long as possible, some older adults may enter LTC early for a variety of reasons, including challenges in navigating health care services, financial barriers to in-home health care, fear of emerging health care needs, and support for unmet non-medical needs [11]. The perceived benefits of direct and continuous access to care support and nursing staff, in turn, reveal drastic gaps in resources available to support older adults who can live mostly independently. By using technologies, such as real-time at-home health monitoring, and implementing AAL systems into living environments, care providers can assess older adults' needs and help ensure they receive the appropriate level of care to maintain their well-being and safety. This proactive approach can help delay the transition from assisted living to LTC facilities [12].

Previous advancements in community-based initiatives for older adults seeking independent living have supported healthy aging among residents who require fewer medical interventions through self-determination, wellness-based services, and the direct provision of community care [13], [14], [15]. However, unlike LTC facilities, existing retirement and assisted living communities lack standardized reporting systems to evaluate and communicate residents' health and wellness needs [13]. An Ontario-based cohort study revealed that, compared to LTC residents, retirement community residents visited emergency departments, hospitals, and alternative levels of care, such as transition or rehabilitation facilities, more frequently, and visited their primary care provider less frequently [13]. Although social inclusion and engagement, community support, and person-directed care are essential for promoting the well-being of older adults [14], existing models applied to retirement communities are failing to address the critical health care needs of their residents.

Furthermore, these models fail to consider the potential for IoT and smart home technologies to bridge the gaps in elder care. These technologies may help to identify individual needs, alleviate some direct caregiving burdens, and improve overall health outcomes. The use of smart home and IoT devices can capture a person's circumstances and obtain a better understanding of their health, providing valuable insights into the support that an individual requires to address shortcomings in their living environment and signalling when interventions may be necessary to prevent poor health outcomes [16]. Although care supports in retirement communities are minimal and intermittent, care providers can reduce the frequency and level of interventions and use their time and resources more efficiently by leveraging existing smart technologies to understand an individual's health and living conditions.

AAL systems and devices can improve lives and can be used to support Canada's aging population [8]. The data from AAL systems can be used to mobilize care and support services if the relevant information is collated and disseminated to trusted care providers. An example of how this may work is outlined in Figure 1. However, a lack of awareness of the potential benefits, and minimal oversight guiding the development and implementation of these technologies, limit the widespread and coordinated deployment of AAL systems to support aging in place [17]. Moreover, the design and implementation of smart living spaces is primarily driven by technology manufacturers and developers [9], [18]. Several factors have contributed to the limited deployment of AAL for aging in place, such as poor interoperability between individual technologies and limited usability of the technologies for older adults [5]. In addition, smart technologies

cannot be implemented in physically or technologically incompatible environments. As such, a key step in facilitating more widespread AAL use is to consider and address existing barriers to installing and using technologies within these living environments.

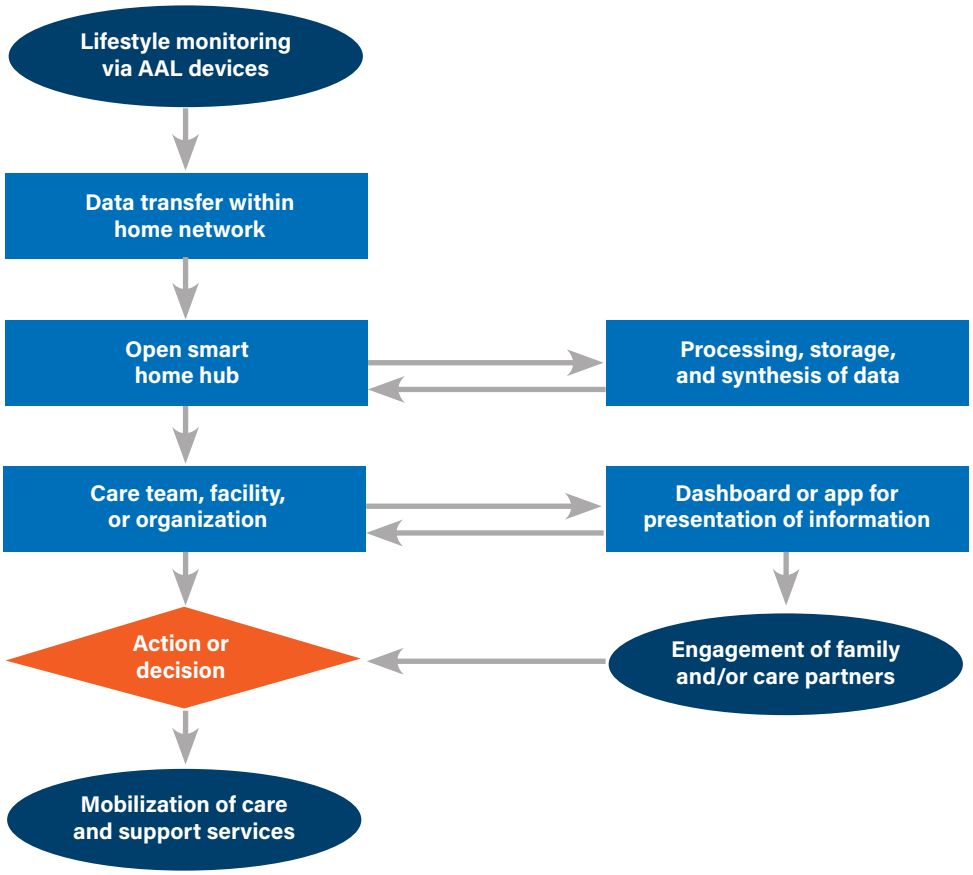
1.2 Research Aims and Objectives

The primary objective of this report is to provide guidance for the integration of AAL technologies in retirement and independent living settings with a focus on the built environment. These guidelines will offer valuable support for retirement facility developers, AAL technology manufacturers, and the architects, contractors, and construction companies involved in retrofitting existing units and constructing new residences. The proposed guidance aims to:

1. define minimum technological requirements for establishing supportive AAL environments;
2. provide best practices for the use of AAL technology, considering the unique needs and characteristics of the infrastructure; and
3. ensure that the built environment is resilient and capable of accommodating existing and emerging AAL technologies.

By developing these guidelines, we aim to support increased deployment of AAL technologies to enhance the quality of life and safety of older adults in retirement and independent living settings through the optimal implementation of AAL technologies in the built environment. To explore the basis of these guidelines, this report will review existing guidelines in

Figure 1: Proposed use of AAL data within care



standards and research (Section 2), explore a sample smart living environment, including various rooms and their requirements (Section 3), and evaluate existing IoT technologies available on the market, as well as emerging AAL trends (Section 4). Finally, this report identifies several gaps and proposes recommendations for the development of smart homes that support older adults (Section 5).

2 Existing Guidelines on Smart Living Environment Design

Given the relatively recent emergence of AAL technologies, there is a limited number of available guidelines that support the integration of AAL technologies in the design of homes and residential environments. However, existing home design guidelines, building considerations, standards, and smart home design recommendations offer valuable insights. Additionally, traditional design principles and best practices can be leveraged to help inform the development of effective and efficient AAL-enabled environments. This section will briefly outline several resources to provide context for the design of AAL-enabled homes and residential living environments.

2.1 Codes and Standards

The National Building Code of Canada (NBC) 2020 [19] details building design requirements in Canada. Developed by the National Research Council of Canada, the NBC presents a model building code that sets the minimum requirements for designing and constructing new buildings and structures, as well as for renovating and retrofitting existing buildings. These requirements address four core objectives, including fire and structural protection of buildings, safety, health, and accessibility. The NBC also addresses energy efficiency and environmental sustainability, including provisions for using renewable energy sources and reducing greenhouse gas emissions.

Although the NBC applies to all provinces and territories in Canada, and each province or territory is responsible for adopting and enforcing the NBC, provincial/territorial officials can tailor these requirements to meet local needs and conditions. Several jurisdictions also have building codes that may be more stringent than the NBC. As such, builders, designers, and property owners must be familiar with all building codes and regulations within their jurisdiction, as non-compliance can lead to fines, penalties, and even legal consequences. To ensure both legal compliance and the safety of buildings and their occupants, it is advisable to consult with a professional engineer or architect for both new builds and retrofits.

For instance, the *Building Code Act* of 1992 is an Ontario provincial legislation that provides the legal framework for the development, implementation, and enforcement of the Ontario Building Code (OBC) [20]. As is the case with all other provincial building codes, the OBC is based on the NBC. The *Building Code Act* in Ontario defines legal regulations, such as enforcement measures for non-compliance or the process for obtaining building permits and inspections, whereas the OBC provides comprehensive technical requirements for all aspects of building construction, including structural design, fire protection, plumbing, electrical systems, HVAC (heating, ventilation, and air conditioning), accessibility, and energy efficiency. The OBC is updated regularly to reflect advancements in building technologies, materials, and construction methods, and addresses emerging issues and concerns in building design and construction. By adhering to the OBC, builders and designers can ensure compliance with essential regulations and create buildings that prioritize safety, accessibility, and energy efficiency.

Although there are numerous building codes in Canada, such as energy codes and building and fire codes [19],[21], there are few information and communication technology (ICT) standards that inform technology implementation within buildings. These standards support the integration of various ICT technologies to support smart home implementation for older adults and inform technology installation, design, monitoring platforms, connectivity, privacy, and cybersecurity. For instance, CSA EXP100:22, *Information and Communication Technology (ICT) Code for Buildings,* includes requirements that support the development of ICT infrastructure in buildings and is scalable for future technology integration [21], although this standard is not specific to living environments nor to the older adult care context.



"There is limited guidance for the safe and effective implementation of technology in smart homes for older adults, which may limit the ability of older adults to access home care."

Beyond the need for additional, older adult-specific ICT standards, equipment standards can provide clarity on which health technologies are beneficial to smart homes that house older adults [22]. Similar to standards that support the management of hospital equipment, there is a need for a standard that supports the management of devices and technologies used in smart homes. For instance, there are standards that require the inspection of medical equipment in medical settings to screen for defects, such as CAN/CSA C22.2, *Medical electrical equipment* [22]; however, no complementary standards have been identified to support the use of medical equipment used in smart homes. As such, there is limited guidance for the safe and effective implementation of technology in smart homes for older adults, which may limit the ability of older adults to access home care [23].

2.2 Best Practices from Research

Although there is a limited body of literature on guidelines and operational considerations for smart home design, this section reviews literature on best practices for developing and implementing AAL and smart home technologies in residential environments. In order to meet individual needs while upholding standards and operational requirements, it is crucial to recognize both the infrastructural and humanistic elements of smart home design. Several existing frameworks and guidelines reflect these considerations and provide valuable insights into effectively planning, developing, and implementing smart home designs.

The Cisco Digital Building Design Guide [24] outlines a series of requirements and considerations for designing and creating smart buildings. The focus of this document is on commercial rather than residential buildings; however, it also provides some key infrastructure recommendations. The section on design considerations outlines the roles and responsibilities of stakeholders involved in the design process. This resource considers the shared interests of residents, building owners, designers, and builders, but does not explicitly consider the end user. Another section proposes system design considerations, spanning network infrastructure design and network standards, data centre infrastructure, and middleware. Cisco also presents a framework for smart building design and development, including an operational roadmap for the design and creation of smart buildings from strategy to construction [24].

Additionally, a recent study identifies key architectural and engineering requirements for designing smart homes in the context of smart city building codes [25]. The study categorizes these requirements into several areas, including green building practices, solar energy and LED lighting, natural ventilation, waste management and recycling, rainwater harvesting, and integrated safety and communication. This research generated a comprehensive framework for designing smart homes that promote sustainability and the efficient use of resources. Discussions of sustainability are especially prudent in light of an increased focus in the fields of biomedicine, health, and engineering

spaces on waste and the high turnover of technologies due to advancements or obsolescence [25]. Although factors such as heating, ventilation, and illumination significantly impact a building's overall sustainability, a truly sustainable living environment must also consider the broader systems, including municipal resources and the life cycle of technologies.

Finally, two valuable frameworks categorize existing IoT and AAL technologies and define the process for smart home modification [26] [27]. These frameworks may serve as a valuable starting point when considering how to adapt already-existing homes, which is likely to be the case for many care recipients. Furthermore, it is important to acknowledge that even in a purpose-built smart home, the needs of the resident may change, and it is important to periodically revisit the home's design. The first framework [26] defines the process for smart home modification in four stages: home assessment, technology selection, design strategy, and user evaluation [26]:

1. Home assessment identifies the requirements for structural modification, layout adjustment, and device applications required to enhance an individual's daily life.
2. Technology selection considers the impact of technology on older adults' daily living, including their acceptance of AAL technology and preference for certain features and controls.
3. Design strategy involves contending with the practical issues of designing and modifying smart living environments, such as architectural elements and older adult needs, and choosing an approach accordingly.
4. User evaluation examines user experiences to guide implementation and inform future best practices of a given device or technology. This evaluation also considers the type of support offered by the technology (e.g., stimulation, accessibility, sensory support, safety, security).

Overall, this framework focuses on devices currently available to consumers and corporations, helping to categorize the many important sensors and tools that can be integrated into smart homes to promote sustainable, independent, and safe living environments that adapt as an individual's needs change [26]. Through this categorization, consumers and corporations might better identify the solutions that best address gaps in the existing home or smart home design.

The second framework [27] examines various application contexts of available technologies in AAL-enabled smart living environments, considering who will use the product, where it will be implemented, and its intended purpose. The target population for product use proposed in this framework includes individuals with characteristics, abilities, and skills that will benefit from the technology. Additionally, the environment in which the product will be used involves considering different solutions from both technological and methodological perspectives. This framework emphasizes that AAL systems offer a broad range of functions—from simple reminders to recording complex observations—and, as such, blanket solutions for an entire population, or even individual members of the population at different points in time, are often not suitable [27]. In the current study, this framework has been implemented to classify the application context of various devices and sensors and establish the requirements necessary for their effective use. Both frameworks described here present valuable insights on smart home system planning and modification, emphasizing the need for a dynamic and personalized approach [26], [27].

3 A Sample Smart Home

While existing guidelines and best practices are useful to understanding the broad considerations of smart home development and modification, the key challenge is considering how these guidelines should be practically applied. In other words, how to tailor them to the needs of a specific care recipient. An example of such an exercise is included here.

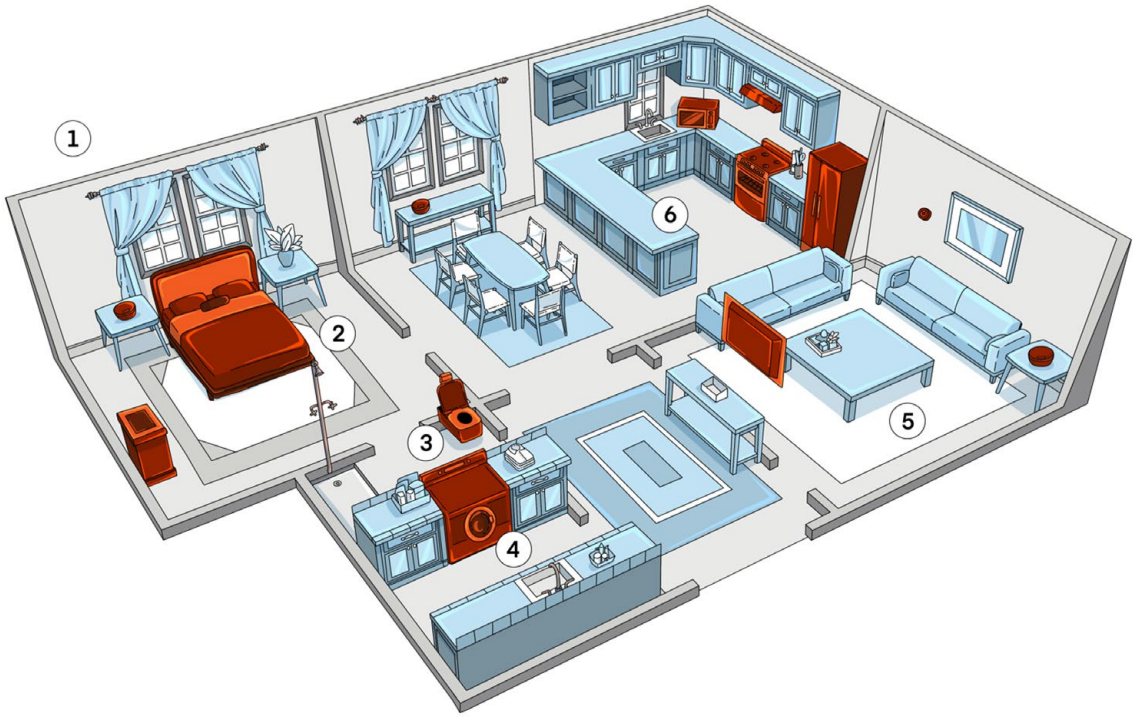
To explore the requirements of a newly built smart living environment, we created a use case centred around a fictional sample smart home for a resident named "Grace", a 79-year-old care recipient. Grace currently lives alone in her own home, but over time her family has noticed a decline in her ability to maintain her home, decreased mood, increased social isolation, and cognitive difficulties. Grace often misses appointments and social events and has experienced

episodes of disorientation. Following a diagnosis of mild cognitive impairment, her family and doctors considered transitioning her to a more supportive care environment, but it is important to Grace that she still be allowed to live independently. As a solution, it was proposed that Grace transition into a newly built retirement community designed to maintain her independence while providing the required assistance to maintain and monitor her health.

A sample smart home from that fictional retirement community is presented in Figure 2, with a room-by-room description of technology requirements and building features described in the following sections. Rooms are numbered to correspond with the associated section in the report, beginning with the general infrastructure of the building (1) and then subsequently numbered rooms (2 to 6). Smart home and IoT devices in Figure 2 are highlighted in dark orange and are listed in the figure caption.

Based on a calculation that evaluated the total draw of similar market-available technologies, there is little added cost to run the technologies used in a smart living environment compared to one without smart devices. However, this estimate is based on commercially available, non-medically regulated AAL and IoT technologies, and does not include medical devices that may have greater power draws [23]. It is critical to also consider the additional costs of the installation, maintenance, and infrastructural set-up associated with these technologies. Additionally, the use case for this model smart home centres around an older adult with a strong support network of family and community members who can assist in setting up and maintaining the smart home. However, we cannot assume that all older adults will have access to similar support networks or access to the means to install, service, and maintain smart home devices.

Figure 2: The Sample Smart Home. Rooms are numbered and smart devices are highlighted in orange. (1) General infrastructure. (2) Bedroom: Smart mattress, sleep monitor, air purifier. (3) Bathroom: Smart toilet. (4) Laundry room: Smart washer and dryer. (5) Living room: Smart television, home virtual assistant, smart thermostat. (6) Kitchen and dining room: Smart microwave, smart stove, smart range hood, smart refrigerator, smart dishwasher (not shown), home virtual assistant (in dining room).



3.1 Overall Infrastructure

Several general infrastructure components are required throughout the smart home, including lights, switches, heating, ventilation, and outlets. It is essential to dedicate time and consideration to strategically place access points and controls for these components. For example, outlets should be positioned to avoid the need for trailing wires, and thermostats and switches should be at a height of no more than 1.2 metres above the ground in unobstructed locations according to CSA/ASC B651-23, *Accessible design for the built environment* [28]. Moreover, prioritizing home automation features where possible can greatly enhance the resident's experience. For example, if Grace were to become disoriented at night, automated lights may be beneficial because she would not need to search for switches in the dark, which might put her at risk of injury or a fall [29]. The yearly power draw and cost of smart or automated alternatives to home hardware (i.e., smart lightbulbs and outlets) are negligible, making them an efficient and economic solution for a smart and safe living environment.

Grace and her care partners may also benefit from basic infrastructure or technologies that are not essential components of a given home but may improve her safety and sense of security. Examples of such technologies include cameras, leak-detection sensors, motion and temperature sensors, and door- and cabinet-opening sensors. As a precaution, and to maintain continuity and data storage, these devices may use backup systems to store a copy of the data. This can be achieved by storing data on the cloud or on a secondary, on-site backup device, such as a hard drive. A limitation of these devices is that they are often battery-powered. This introduces an additional serviceability consideration, where regular monitoring of battery levels and occasional replacement are required to ensure their continued functionality and reliability.

Another key consideration in the design of a smart home system is the strategy for integrating local devices on the local area network (LAN) and deciding on appropriate levels of required Internet connectivity and the amount of data that are shared with third parties. An example of how the data network, smart home hub, and user interfaces work together was illustrated in Figure 1. The network includes a standards-based internet protocol (IP) network that acts as a central system that connects the devices around the home [24], [30]. The retirement community that Grace is moving into would have taken steps when establishing the community to ensure that the network can bear the load of devices from several units. A normal residential network only offers address space for 254 devices, meaning networks can quickly become full if several residents' smart homes are operating on it simultaneously. As such, the community would need to use shared networks for smart home devices or invest in commercial-grade networks that can support the needed number of devices.

To form a holistic analytical view of the assisted living smart home, devices must report their data back to some form of central repository [24], [30]. Although smart home device communications can occur both over wired and wireless connects, wireless connections using various frequency bands are by far the most common due to factors such as the cost to install and ease of use. Furthering the need for inter-device communication, a home or set of homes within a retirement community can only be managed if digital communication between the smart home and a management device is possible. This centralized network provides a way to connect the activity of the home to a manageable central source, as well as to manage an energy consumption profile. Within an individual home, such as the one in which Grace will live, an open smart home hub (i.e., one that is compatible with devices across manufacturers) would communicate according to standard protocols to allow connection with any smart device or sensor [30]. Such smart home hubs should ideally be centrally managed by care or community management personnel to facilitate the provision of care. This centralized management would require a user interface that service providers and community managers could securely interact with, as well as a home-specific, client-facing portal for Grace and her care partners. However, further research and development is necessary to define the requirements of this interface.

3.2 Bedroom

The bedroom is a private area of the home, designed to prioritize comfort and rest. Given that older adults often spend a significant amount of time in their bedrooms, it is necessary to ensure that these spaces are equipped to meet the older adult's unique needs and maintain their safety and comfort throughout the night. To ensure these needs are met, technologies, such as a smart mattress, sleep monitor, and air purifier, may be integrated into the bedroom. When designing this space, key considerations centre on ensuring that the older adult can navigate their bedroom without encountering clutter or obstructions, thereby mitigating the risk of falls and accidents. It is also necessary to consider whether an older adult can easily get in and out of bed independently, or whether mobility aids (e.g., bed rails or adjustable bed frame) are required to facilitate transitions to and from the bed. Prioritizing these elements will contribute to the older adult's feelings of safety and independence in their bedroom.

Like most older adults, Grace aims to sleep for seven to nine hours a day [31]. Given that an individual's quality of sleep can significantly impact daily functioning and poor sleep can contribute to cognitive and mental health issues [32], Grace's smart bed helps monitor the duration and quality of her sleep, alerting her care providers to changes in her sleep patterns that may impact health outcomes. To optimize safety and aesthetics, ambient sensing and environment control technologies (e.g., an air quality monitor) are placed around the perimeter of the room with the aim of reducing clutter and minimizing visible wiring. As these technologies are not mounted, they offer flexibility in positioning and can be easily reconfigured or moved at Grace's request.

3.3 Bathroom

Bathrooms can present several safety challenges for older adults, including slippery floors and mobility challenges while transferring in and out of the bathtub or using the toilet. Although there are minimal smart technologies explicitly designed to enhance bathroom accessibility and usability for older adults, various low-tech assistive and adaptive infrastructure components can be used to modify bathroom spaces. These include curb-less, "step-in" showers, shower chairs, sprayer attachments for shower heads, grab bars and rails, motion-activated and contactless flushing for toilets, and raised toilet heights. Although these technologies are commercially available, they do not integrate Internet or communication features, making them non-smart solutions. That said, there is increasing interest in wastewater monitoring as a surveillance tool [33], which may increase the prevalence of smart bathroom components available on the market in coming years. Grace may be interested in such a solution because it could provide her doctors with insights into her internal health that otherwise would be difficult or embarrassing to discuss.

3.4 Laundry Room

Laundry may present specific challenges for older adults due to possible physical limitations, including the weight of laundry and large detergent containers, transferring clothes between appliances, or hanging laundry for those who do not have a dryer. Furthermore, older adults with dementia or memory loss, for which Grace is showing some early indicators, may struggle to remember this chore, recall the necessary steps, or forget to transfer loads between machines. Many older adults may delegate laundry tasks to community services, family, or caregivers. However, several smart technology solutions can aid older adults in completing laundry independently, which may still be preferred. These smart machines are equipped with intuitive features and controls that can support older adults, including pre-set cycles, self-dispensing detergent systems, and cellular alerts to notify older adults or caregivers when a load is complete or has remained in the machine for some time. Smart laundry machines can also reduce energy consumption and household energy costs. Given their long lifespan in the home and their unlikely relocation once installed, careful consideration from builders and designers is necessary to select design the laundry area, select the appliances, and place them accordingly.

3.5 Living Room

Grace wants her living room to serve as an entertainment space for relaxation, hosting, and other leisure. IoT technologies in the proposed sample smart home that can further these goals include a smart television and home virtual assistant. There has been increasing interest in the AAL space for smart televisions because of how they could be used to promote physical activity and communication [34], [35], as well as the potential to examine usage data from these devices to gain insights into the mental wellbeing of residents [36]. The smart thermostat can also be placed in this room, as it is a central living space, at a height of no more than 1.2 metres [28]. Lastly, the home virtual assistant may be used for home automation purposes, such as turning lights on and off or for entertainment, such as reading out the news or playing music. When designing this living space, key priorities should be comfort and aesthetics. For instance, Grace may prefer to maintain a certain style and keep more "medical-looking" or assistive technologies out of sight [37]. Ideally, any technologies present in this room should be unobtrusive and thoughtfully integrated to blend with her preferred decor. The smart television in the sample smart home is also mounted, requiring installation on a weight-bearing wall with wall studs, and with electrical outlets positioned appropriately. Lastly, the home virtual assistant is placed on a side table, taking care to avoid trailing wires to prevent potential trip hazards.

3.6 Kitchen and Dining Room

Kitchens and dining rooms are multi-purpose spaces in an individual's house that are used for cooking and gathering. When designing these spaces and selecting appliances, builders must prioritize safety and accessibility for older adults. Safety considerations include the management of hot surfaces, ease of item transportation, and minimal bending and reaching requirements. Concurrently, builders should focus on maintaining and enhancing independence through the implementation of simple smart solutions and product features, such as ring tones and chimes for various appliances, simplified appliance controls, and intuitive actions. The smart technologies included in the model home kitchen and dining room consider a range of smart technologies to support these objectives, supporting Grace's safety and independence while potentially providing insights into her activities of daily living. These include a smart refrigerator, smart stove range, smart microwave, smart dishwasher, and a virtual home assistant. The virtual home assistant in this room may serve many of the same functions as the one in the living room, and Grace may enjoy the convenience of having one here as well. However, another benefit of a virtual home assistant is its ability to remind and alert, which may be particularly useful here. For example, as she prepares and eats breakfast, it would be helpful for Grace to be reminded about the medications she needs to take with her meal or appointments she has that day. These smart appliances offer convenience, ease of use, and enhanced functionality that cater to the unique needs of older adults while promoting an independent and efficient living experience.

4 Technology Evaluation

Our research team used a bottom-up approach to understand the requirements of a smart home. Due to limited oversight and guidance, technology manufacturers have shaped the space [8], [9], [26]. To identify smart home requirements, we examined technologies currently available on the market and those under commercial development. Our technology evaluation included 156 unique technologies from 143 vendors. The initial list was developed based on previous work by our research team [18], and the technologies were examined for relevance to the current project and their technology readiness level (TRL). Here, TRL refers to the technology's level of maturity for commercial availability on a nine-point scale [38]. We identified additional technologies through a comprehensive search of academic and grey literature from databases such as Scopus, PubMed, Google Scholar, and Google Search. We sought out existing and emerging technologies that (a) were developed for or are being used to sustain healthy



"Builders should focus on maintaining and enhancing independence through the implementation of simple smart solutions and product features."

behaviours, provide preventive remote care, or assist with daily living activities, and (b) are defined as IoT, mHealth, wearables, smart homes systems, or smart home technology suites. The resources we reviewed included technical papers, reports, and academic literature focused on health technology implementations. Regulated medical devices and equipment (e.g., CPAP machines, hospital beds) were not included in this evaluation to maintain the focus on consumer-level AAL; however, the development of future guidance should consider their role and requirements within a smart home based on identified best practices [23].

Next, the team consulted the product pages of each technology to identify the vendor information, purpose, application, and TRL. The compiled list was then carefully reviewed and discussed with the research team to eliminate duplicates or irrelevant technologies. To examine implementation requirements of these technologies in a smart home, three members of the research team were each assigned two to three potential building requirements for each technology. These requirements included power, Internet, internal network, water, sewer, mounting, HVAC, and gas infrastructure. This information was sourced from product pages, vendor websites, research articles, and product reviews. A summary of all evaluated technologies, their TRLs, applications, and requirements is available in Appendix A. Throughout this evaluation, the research team also noted any patterns or discrepancies within the building requirements. These evaluations allowed us to identify common themes and potential challenges across these devices in a smart home environment. Based on these insights, the research team developed a series of recommendations for each technology. These recommendations are detailed in Section 4.2 of this report.

4.1 Types of Smart Home Technologies

From the 156 technologies evaluated, 150 were commercially available. Although most of the technologies evaluated here were stand-alone devices, some were sold in the form of device packages ("suites") or integrated into larger data-sharing infrastructures ("platforms"). Through an inductive, bottom-up evaluation, technologies were classified into nine distinct application types:

- **Assessment:** Technologies that include smart devices for measuring vital signs and basic health indicators (e.g., temperature, heart rate, balance) that may be used by a care recipient or their care provider. These measurements typically provide instant readings or can be used to provide a series of measurements for observing general trends. This application type was uncommon, representing only four of the 156 (2.6%) technologies evaluated.
- **Chronic condition monitoring:** Suites and platforms intended to help care recipients manage specific chronic conditions (e.g., diabetes, Parkinson's Disease, chronic obstructive pulmonary disease)

and track symptoms and treatments. This application of smart home technologies was also uncommon, only constituting six of the 156 (3.8%) technologies evaluated. The sophisticated nature of these chronic condition monitoring devices may explain their limited commercial availability.

- **Data sharing:** Suites and platforms that consolidate health and IoT data for clinical and research applications. Eight of the 156 (5.1%) technologies evaluated were classified as data-sharing technologies.
- **Fitness:** Devices and suites meant to encourage, track, or support physical activity and movement for care recipients. Although fitness features are common in health monitoring applications, few applications focused exclusively on physical activity. They represented only four of the 156 (2.6%) technologies.
- **Home environment monitoring and control:** Technologies that manage aspects of the home environment, such as lighting, temperature, humidity, and security. The variety of these devices allows individuals to tailor technologies to their distinct needs. Ensuring integration with other smart home monitoring systems is crucial to create a cohesive smart home environment. These were relatively common technologies, representing 26 of the 156 (16.7%) technologies evaluated.
- **Housekeeping:** Devices that support instrumental daily living activities, typically by incorporating sensors and IoT concepts into everyday appliances (e.g., refrigerators, washing machines, vacuum cleaners). Although there is a demand for housekeeping technologies that support daily living activities, a limited number of commercial applications are available. Housekeeping technologies appeared in nine of the 156 (5.8%) technologies evaluated.
- **Personal assistants:** These technologies typically take the form of AI-powered speakers that allow users to control other IoT devices in the home. Personal assistants were uncommon, representing only two of the 156 (1.3%) technologies.
- **Personal health monitoring:** These devices and suites enable users to monitor specific health and well-being variables, including weight, sleep, glucose, neurological symptoms, or a combination of these. This was a relatively common application type, representing 36 of the 156 (23%) technologies. The variety of personal health monitoring applications allows individuals to tailor commercially available technologies to their unique health care needs and goals.
- **Remote patient monitoring: D**evices and platforms that allow health care providers to remotely monitor care recipients, often integrating with electronic health records or telehealth platforms. This was a very common application type, representing 60 of the 156 (46%) technologies that were evaluated.

4.2 Building Requirements

4.2.1 Physical Building Requirements

Physical building requirements include various aspects of a home's infrastructure, including mounting, water and sewerage, gas, and heating, ventilation, and air conditioning (HVAC) systems. Here, mounting refers to the installation of sensors, devices, or suites that prepares a product for use. Mounting may involve setting, backing, or securing a product to the floor, wall, ceiling, or other surface. Water requirements involve all sources of water supply and output within the infrastructure of a home, including appliances. Sewerage is an implicit part of water requirements and refers to infrastructure that carries water and sewage (including "grey" and "black" water) out of the home and into receiving structures, which may be stand-alone (i.e., a septic tank) or part of regional infrastructure. Fuels such as natural gas or propane are used to provide power in some homes and buildings, and are primarily used for heating, cooking appliances, and electricity. Lastly, HVAC systems are integrated and control the temperature, humidity, and air quality in an enclosed space.

When considering building requirements, it is necessary to consider the complexity and concealment of integrated systems and the intersection of various

components. For this analysis, each technology was assessed for specific building requirements (i.e., mounting, water, sewerage, HVAC, and gas) by reviewing its available product information, then categorized relative to its characteristics. This analysis found that few prescribed or specialized physical requirements were identified among the evaluated technologies. For example, water and sewerage were uncommon building requirements among IoT devices; however, installations of smart accessories, such as smart replacements for existing fixtures or water monitors, may be added to help reduce waste (see Section 4.3.1 for more on the increasing interest in wastewater monitoring). HVAC and gas requirements are highly dependent on specific product features and the power source for the building (i.e., natural gas, electric, or propane). This factor is critical to evaluate compatibility with existing infrastructure, especially in rural and remote areas. Full details on the physical building requirements of the devices analyzed can be found in Appendix B.1.

Home environments are typically equipped with the necessary infrastructure to support large devices (e.g., smart refrigerators, smart stoves, smart washers and dryers). However, it is critical to consider compatibility with existing infrastructure, particularly in older homes where spaces such as kitchens and laundry rooms may be designed for appliances that differ in size from available smart products. Building an AAL-enabled smart home for an older adult differs from a typical home set-up in its need to accommodate physical networks or power infrastructure for smart devices, as well as any medical devices in the resident's home [23]. Indeed, visible wiring should be minimized or concealed wherever possible, not only for aesthetics but also for safety reasons. Physical infrastructure should be compatible with the transmission of wireless signals, and hubs need to be positioned to minimize signal distance. Furthermore, cameras and motion detection sensors require a relatively open field of view. These environments should be designed in a way that prioritizes ideal device placement, a wide field of view, and minimal wiring.

4.2.1.1 Building Accessibility

Standards for living spaces provide recommendations and requirements to support a building's accessibility and usability. These standards present best practices to minimize physical and technological barriers and promote inclusivity for individuals with physical, sensory, or cognitive disabilities [39], [28]. Three standards offer specific recommendations for structural design and construction practices, emergency evacuation, residential accommodation, and vehicle access. Standards for the built environment include CSA/ASC B651-23, *Accessible design for the built environment,* [28] ISO 21542:2021 and *Building construction – Accessibility and usability of the built environment* [40]. CSA/ASC B652:25, *Accessible Dwellings* [41] provides detailed guidelines on operating controls (such as thermostats, receptacles, electric panels, light switches, appliances, and intercoms), including their location and illumination. The standard offers recommendations for keeping floor spaces clear and specifications for objects fixed to walls. It also addresses home automation to support a wide range of physical, sensory, and cognitive disabilities, aiming to make dwellings accessible to all individuals. This standard aligns with Universal Design principles, which promote the development of accessible environments that support all ages, sizes, and abilities [41]. Together, standards that provide recommendations for the built environment are required to develop new standards, which will support the implementation of AAL technologies in smart communities. These standards identify minimum requirements recommended for constructing new accessible buildings and provide recommendations for modifying existing buildings to accommodate accessibility needs [28], [40].

4.2.2 Electrical Building Requirements

In the context of smart home technologies, the number and integration of smart devices impacts the overall power draw on the home's system. Building power systems can be complex and interconnected and may consist of one or several parallel systems simultaneously supporting utilities such as HVAC,

lighting, and security [42], [43]. Smart home technologies offer users greater control and flexibility over their energy consumption, potentially enhancing their home's energy efficiency [44]. Furthermore, smart home technologies are not only beneficial in supporting individual health and well-being, but also contribute to reduced utility costs and a smaller carbon footprint [45]. To analyze the electrical building requirements, the available product information was reviewed so that devices could be categorized based on the way in which the device uses or draws electricity. However, this analysis found that integrating energy-efficient building solutions introduces specific challenges due to broad variations in power requirements across products [42]. A summary of this analysis can be found in Appendix B.2.

Exposed cabling (i.e., consumer-grade AC cable or even other exposed cables for Internet connectivity such as ethernet) in an AAL-enabled smart home should be minimized, while ensuring serviceability is retained. In Section 3.1, we described ideal placement of outlets and use of in-wall wiring based on the device, allowing for flexibility in home design according to the resident's needs and preferences. A future standard may guide builders on the recommended number and placement of outlets, necessary hardware, and recommended distances between outlets and wiring installations.

Publicly available product information contained inconsistencies in specified power requirements. Some product descriptions included the power requirements of a specific product, whereas others lacked this information. Additionally, power requirements varied widely across smart home technologies based on their usage (e.g., a smart oven will draw more power than a smart door lock). Lastly, once the physical structures are built, it is essential to consider the trade-off between power sources and usability in the selection of smart devices for a specific living environment. For example, battery-operated devices require recharging or replacement, whereas wired options may have a limited range of use.

4.2.3 Connectivity

Connectivity in the context of IoT refers to how devices connect and communicate across networks and with other devices while requiring minimal user intervention [46]. To analyze the connectivity requirements, the available product information was reviewed so that devices could be categorized based on whether they require an Internet connection and what that connectivity involves. Specific building requirements for connectivity include the Internet and internal networks (e.g., wired LAN, Matter, Wi-Fi mesh, powerline). The Internet requirement pertains to whether a device needs to be connected to the Internet to function, whereas the internal network describes the device's local connections (e.g., hub, mobile app on the user's devices). Due to the current industry tendency toward the increased use of cloud platforms, it has become increasingly rare to find mobile applications that interface directly with smart home devices without requiring an external Internet connection. This is an important distinction, because although it is theoretically possible to have a smart home device that interfaces directly with software on a patient's or care provider's smart phone, tablet, or computer, the majority of consumer-facing devices require a network connection to enable this communication. Together, the Internet and internal networks enable physical devices in a living environment to become smart technologies [26]. In other words, this connectivity integrates users' behaviours, needs, and living environment, thereby enabling the collection of personal health information in provider platforms, diagnostic systems, and databases [26]. A summary of this analysis can be found in Appendix B.3.

From a systems perspective, devices fall broadly into two categories: stand-alone and hub-based. Stand-alone devices are cheaper and feature a combination of Wi-Fi and Bluetooth for data connections. They will often communicate directly with a single smart phone or tablet, making it difficult to provide access to other users (e.g., other care providers, the resident's care partners). Furthermore, these devices are all IP-based

and will therefore result in more congestion on a user's network. These devices are generally easy to set up but also offer slower and less reliable wireless connections, especially in congested urban areas where there are many radio frequencies in any given area. This can present significant systems design issues when considering large smart communities, since the devices would be communicating wirelessly, and a surplus of radio interference can cause delays and/or connectivity issues. Hub-based systems are generally more expensive and involve the added cost of purchasing a centralized smart home hub to connect to all the devices. They typically use protocols that lie outside of the conventional Wi-Fi and Bluetooth spectrum and can generally offer faster device response times and more reliable connectivity. They will often not take up individual IP addresses on the network, instead offering a system where the hub is the only IP-based device, and the actual smart home devices exist on a separate network using their own protocol.

This review demonstrated that although most smart home devices offer Wi-Fi functionality, some can function without it. However, it is critical to consider the security and privacy of the personal health information collected by smart devices and stored on the internal network (i.e., LAN). Understanding the oversight of the network, data collection, storage, distribution, and management is vital to establishing trust and acceptance of smart devices among users. Additionally, consideration should be given to the volume of devices that require Internet access and the bandwidth of a user's home Wi-Fi allowance to ensure the smooth connectivity and operation of smart technologies.

4.2.3.1 Limitations of Internet Connectivity

It is important to understand the limitations associated with Internet usage because high-speed Internet is often required to support the demands of smart home devices. For instance, smart homes equipped with medical or monitoring devices to assist older adults require continuous connectivity. High-speed Internet uses high-quality and high bandwidth capacity, such as broadband to deliver high-speed Internet.

Depending on the broadband technology in use, there may be limitations to the Internet speed. For example, fibre optic cables can support higher Internet speed compared to Digital Subscriber Line (DSL). Less advanced broadband technology, such as DSL, may result in slower Internet speeds, potentially compromising the connectivity between devices and the functionality of smart home devices.

Internet speed can pose a significant challenge for facilities that lack the required broadband infrastructure to support the demand for high-speed Internet. This is particularly true for rural and remote areas where the population is small and providers may not invest in advanced broadband infrastructure, resulting in slower Internet speeds. In addition to considering the smart home's bandwidth usage, the bandwidth usage of the older adults living in the home should also be considered. The limitations of Internet bandwidth and connectivity may raise concerns about managing power outages and cases when the Internet network is unresponsive or extremely slow. In such cases, it may be helpful to have a backup Internet provider that uses a different transmission (e.g., cellular, satellite) or a home generator.

4.2.3.2 Backup 5G Routers and Home Generators

Internet connections can be lost for various reasons, and that loss poses a challenge for the continuous connectivity required by smart home devices. When Internet disruptions occur, there are a couple of solutions that may be effective. One option is to use backup Internet sources, such as mobile 5G routers [43]. These routers can be particularly useful when the Internet network is unresponsive or during power outages [43]. However, they only provide temporary Internet connectivity as they need to be charged after the battery runs out [44]. Additionally, if devices need continuous power and are not powered using a battery, they may shut down despite Internet availability through the mobile router. Therefore, 5G routers may not be suitable if an older adult resident uses a vital health device that requires a continuous power source. Another solution is to use backup generators to power the home system during power outages [45]. These



"The technology review described in this report identified several trends that do not necessarily correspond to particular devices, but rather are expected to strongly impact the future development of AAL-enabled smart homes."

generators can be particularly beneficial for powering vital medical devices and equipment [45].

Despite these options, Internet connection loss can still occur for a variety of reasons, including infrastructure limitations or damage to existing infrastructure. To address such scenarios, smart home devices should have an offline mode to ensure data are saved even in the absence of Internet connectivity. When home devices are in offline mode, they use the LAN to store data while the Internet connectivity is unavailable [46]. This mode is intended for temporary use until the devices are reconnected to the Internet [46]. Once the devices regain Internet connection, the connectivity between devices is restored, and the devices are synchronized [47].

4.3 Key Trends in AAL Technology

The technology review described in this report identified several trends that do not necessarily correspond to particular devices, but rather are expected to strongly impact the future development of AAL-enabled smart homes. As such, these trends are discussed in this section as general approaches.

4.3.1 Lifestyle Monitoring, AI, and Predictive Models

A key area of interest for AAL is the ability to use these systems to be more proactive in older adult care, allowing care providers to take steps to protect or improve health and well-being before the occurrence of an adverse event [48], [49]. This would enable care providers and community managers to leverage AAL systems to anticipate the needs of the care recipient and determine whether adjustments or interventions are required. This can be achieved through AI-driven lifestyle monitoring, which uses data gathered by AAL devices to gain insights into the daily routines and activities of care recipients [48], [49]. Once the system identifies patterns in the care recipient's activities and routines, it may be able to detect anomalies in their behaviour or declines in functioning, which can trigger care services [50]. Although there are currently no well-established solutions with demonstrated efficacy, this remains an area of great interest for both developers and potential users [51], [52].

Most initiatives in this area use data collected from existing ambient sensors, such as temperature or noise detectors, to provide insights into daily activities [53], [54]. However, new forms and applications of sensors are also being considered for more accurate lifestyle monitoring [47], [50]. For example, analyzing bodily excretions, such as urine or feces, to understand markers of health is a growing area of interest. Wastewater monitoring of sewerage systems has recently seen increased use as a public health surveillance tool [55]; however, there is also interest in applying this type of monitoring on a smaller scale, including waste collected in a home toilet [56]. This approach is particularly valuable as it offers a non-invasive and low-effort method to collect data on

biomarkers in a care recipient's body, which may help identify changes in their health [56].

Despite the great potential of AI-driven lifestyle monitoring, it does raise ethical and privacy concerns [57], [58]. Lifestyle monitoring offers a much more intimate look into an older adult's daily activities than other, more traditional forms of assessment; therefore, it is essential to ensure that data are well-protected. Additionally, clear communication with the care recipient and their care partners is crucial so they understand what data are collected and used, the benefits of this monitoring, and the care recipient's own rights.

4.3.2 Integration and Interoperability

Another key requirement is the transition from proprietary technologies within isolated systems to an ecosystem that facilitates seamless flow. A foundational aspect of this transition is interoperability, or the ability of devices in the smart home to interface with one another and with data sharing or platform management [31]. However, achieving interoperability is often challenging due to design incompatibilities among different devices and components and a lack of universally accepted data-sharing standards [31], [59]. This incompatibility is often intentional, stemming from competition between different vendors, but it nonetheless presents a barrier to data flow [31]. Using devices independently also presents a considerable challenge for users, as it typically means that information from each device is accessible on a different platform. As the number of devices increases, this could potentially become more difficult to manage [30], [50].

A valuable case study here is that of the Matter Consortium [50]. Matter was designed to be a universal connectivity standard to allow IP-based cross-platform integration of devices within smart homes, thereby eliminating the need for bridges or hubs [50]. However, since this innovation comes from the private sector, there remains a need for independent standards driven by research into communication platforms and commercialization, specifically within the health care and public health sectors. In Canada, the inter-institutional Program to Accelerate Technologies for Homecare, also known as the PATH platform, is an example of a relevant research initiative. This program proposes to integrate several communication protocols to connect devices and sensors to a cloud-based AI engine [51].

4.3.3 Centralized Data Strategies

Centralized data-sharing strategies concentrate the data collected from smart homes into a single location [52]. These strategies may include storing select data on a local server or a remote cloud-based platform. The details of the data strategy will likely vary depending on the living environment. For example, the centralized data-sharing strategy for an older adult living independently would differ from that of an older adult residing in a community care organization such as a retirement home. The care organization likely shares the same network and infrastructure, which raises questions about privacy, primarily concerning who will have access to the personal information gathered from AAL devices. Both in independent living and community care organizations, some older adults may have concerns about the privacy of their information, a loss of independence, and dependence on technology [53]. The fear of losing independence may be influenced by a fear that health care providers might act on the information gathered from the AAL devices in a way that is undesirable to them, such as recommending more monitoring or an intensive care setting to family members [53]. It also remains unclear who will have access to the data and who will be responsible for decision-making based on data gathered in Canada. Older adults living independently may share their data with a centralized location, their care partners, care professionals, and allied care professionals. However, in the case of care organizations, it is unclear how the data would be managed within the organization and shared with the older adults and possibly their care partners, care providers, paraprofessionals, or allied care professionals. Paraprofessionals include housekeeping, transportation, and meal deliveries.

Care organizations are likely to have integrated networks that enable patient smart home systems to be unified with a shared back-end infrastructure. To ensure the sustainability and scalability of the infrastructure, three core elements should be

considered for implementing integrated networks. First, proper network management practices, which may include managing wireless connections to prevent congestion, monitoring the consistency and reliability of the networks, and working to ensure the interoperability of new devices [54]. Next, data structure and access, which may include adopting a standard data format, using a semantic model to improve interoperability, and considering security measures [55]. Finally, resiliency, which is the system's ability to recover from challenges such as disaster data recovery [54], [55]. These factors are important to consider when planning a centralized data strategy, whether the health care recipient is living independently or in a more formal setting.

4.3.4 Circle of Care Integration

As highlighted in the previous section, care recipients, care partners, care providers, allied care professionals, and paraprofessionals may need access to information gathered from AAL devices to support the health of older adults. However, it is important to consider how this information will be shared with the care recipient |in a manner that is both clear and interpretable. Given that some older adults may not feel comfortable with technology, and health care providers may require easy-to-access information, it is crucial to ensure that their information is as user-friendly as possible to prevent confusion or frustration [66]. Consequently, the user interface should be easy to navigate, both on an app and a web browser. As some care recipients may require additional context to understand some information, it may be beneficial to include guidance on how to interpret their data.

5 Recommendations for Smart Home Development

5.1 General Guidance

Whether the smart living environment in question is a retrofit of an existing residence or an entirely new build, there are some core factors to consider. The primary concern is to avoid clutter and maintain clear pathways for movement. This includes minimizing the length of trailing cables on floors, ensuing they are flush against walls, and avoiding pooling or looping of cables, particularly preventing any intersection with movement pathways. Furthermore, the placement of technologies should comply with accessibility guidelines such as those outlined in CSA/ASC B651-23 [28] and ISO 21542:2021 [40]. For instance, wall-mounted controls for AAL devices should be no higher than 1.2 metres and wheelchair-navigable pathways should be at least 1.2 metres wide. Lastly, considerations around comfort and aesthetics should not be overlooked, and care should be taken to avoid excessive visible wiring, busy surfaces, or anything else that might detract from a comfortable and "homey" environment [37].

Although not visible in the sample smart home exercise, the requirements of installed sensors, smart cameras, infrared cameras, etc. that monitor health or environment indicators should be considered. As these devices require a good field of view, the ideal placement of such sensors is typically either on the ceiling or in the corner of a room [56]. This requires reinforcement of relevant areas for properly mounting and placing outlets in these locations to minimize wires in the environment. Therefore, each corner of the room should have at least one outlet. In also may be worth considering placing ceiling outlets near the corners of rooms. Many of these devices also have high network needs. High-quality cables could help address these issues, particularly if electricity is supplied via the same cables as the Internet connection (i.e., Power over Ethernet (PoE)) [24].

Interoperability and data-sharing strategies are also critical to integrate into smart living environments. In Canada, efforts are already underway to establish regulations for data exchange that cover wireless devices, including smart home devices, which fall under the purview of Innovation, Science and Economic Development Canada (ISED) [57]. Additionally, Industry Canada, which has now merged with ISED, has developed technical specifications for wireless communication devices commonly used in smart home devices, such as Zigbee and Z-Wave [57]. However, there is still a lack of guidance for the integration of IoT and AAL technologies into both existing structures and new buildings. As we develop standards, it would be valuable to draw insights from

the experiences of other countries that have regulated this rapidly growing industry. Notable examples include the European Union's General Data Protection Regulation (GDPR) [58], which governs the collection, storage, and use of personal data, and the EU's Radio Equipment Directive (RED) [59], which addresses wireless communications and cybersecurity issues for smart home devices.

When selecting technologies to implement, a primary consideration should be the privacy of older adults as they perform daily activities within their homes. This is an integral part of a wider conversation around trust, where older adults and their care partners want assurance that their data are safeguarded, thereby reducing perceived infringements on freedom and security [60], [61]. Although this should be prioritized within data management structures, the extent to which this is done will vary across technologies and systems [62]. Several tools and frameworks have been proposed to maintain the security of IoT for smart homes. These include the management of cloud-based infrastructures as a whole [63], automatically configuring new IoT devices added to the home's network [63], [64], and setting access privileges for various users who might need to access the data from the IoT device network to provide care [65].

From a design perspective, many simple strategies can be employed to safeguard residents' privacy when choosing IoT devices and designing the data infrastructure of a smart living environment. One such strategy is data localization [66], which involves the storage and processing of IoT data locally rather than on a remote cloud server [66]. Although cloud storage is commonly used for IoT data storage [67], there are notable advantages to implementing localized solutions wherever possible [66]. In a practical sense, this may enable selecting devices that store their secure access information locally, eliminating the need to access a remote authentication database or even maintaining local servers. This approach may enhance privacy; however, it could increase costs, rendering this option not viable for many operations.

Lastly, smart living environment design for an older adult should not assume that no further changes are needed once the environment is implemented [27]. Planning and allocation of resources should be done in advance to allow for flexibility in modifying the environment to suit the older adults' needs and preferences, as well as the changing technologies [26]. The design of the home should be periodically revisited to ensure it is still appropriate for the resident's needs, and to make appropriate adjustments as needed. Guidance for considerations in creating these modification plans is outlined in [26]; however, community developers should also consider the cost of maintenance and modification in their budgets.

5.2 Retrofits

In Canada, most older adults prefer to stay in their homes as they age rather than relocating to a new environment [2], [68]. Smart home technologies can play a crucial role in supporting this goal, enabling people to remain within their preferred settings, access the necessary services, and maintain their social connections, all while enjoying the benefits of AAL solutions [2]. However, retrofitting older homes to integrate these systems presents some unique challenges that emerged from the technology review completed for this report.

One fundamental challenge is the potential incompatibility between smart technologies on the market and the existing infrastructure of the building. For example, many smart appliances draw significant power that, when combined, may strain an older building's electrical system. Furthermore, hosting many IoT devices on the same network may consume significant Internet bandwidth, potentially requiring a new package from the internet provider.

Conducting an evaluation similar to that outlined in Section 3 of this report may assist in determining what is feasible for the home and within the residents' budget. Another important consideration relates to the physical structure of the home, which may be outdated or ill-suited for accommodating certain smart technologies. For example, if a kitchen was built to fit a refrigerator and oven of a certain width, but their smart counterparts are not available in the same dimensions, significant additional costs might be incurred to modify the kitchen. Similarly, there may be walls that cannot

accommodate additional wiring or surfaces that cannot support the weight of new devices. These considerations are crucial when deciding the extent of a retrofit and should be factored into the overall cost of integrating AAL technologies.

Another issue that emerges is the potential disruption to the residents' lives. As previously described, retrofits may be extensive or require an overhaul of a building's existing infrastructure, which might require residents to temporarily vacate the space. This displacement, whether direct (i.e., older adults cannot stay in the same residential unit) or indirect (i.e., their living environment is drastically changed), can expose older adults to increased social, financial, and mental health risks [69]. Even without extensive home modifications, the integration of some smart home devices requires special installation by an electrician, which may require a temporary power shutdown.

Another concern is the potential overall impact on a familiar and comfortable living environment. Retrofitting a home to include AAL systems aims to maintain comfort and familiarity within a space; however, it may require adding more products to enhance existing devices, leading to clutter in an enclosed space. The accumulation of devices may distress older adults, as it could make a space feel more clinical and less like home, possibly contributing to a perception of frailty that they may find unsettling [70]. Furthermore, it may interfere with the older adults' ability to locate and operate devices in their environment, leading to confusion and frustration. To address this, it is essential to minimize additional clutter, particularly on countertops and furniture, and to eliminate the presence of wires on the floor. It also may be preferable to choose sleeker, lower-profile devices to maintain the aesthetic and familiarity of a living space [70].

Lastly, there are potential complications in integrating IoT devices into existing networks. For example, it is necessary to consider whether any products brought into the smart living environment will retain the memory of networks and devices to which they were previously connected. For serviceability purposes, it is important to consider whether a user is repeating the set-up process or integrating the device into an existing network, which may impact the configuration and compatibility of a device within the current network.

5.3 New Builds

Although living independently in their own homes is the planned and preferred living arrangement for older adults in Canada, there are instances where an individual's current home living environment may no longer be safe or suitable for their health and well-being [71]. Transitioning to new builds may initially detract from an older adult's comfort and autonomy; however, it offers the advantage of having the necessary supports in place to allow older adults to live independently in their homes for longer. In this context, aging in place is achieved by planning and implementing personalized supports based on the individual's characteristics [72], and designing a living environment that can adapt to the older adult's needs over time [73].

Aging is often accompanied by a decline in physical and cognitive function, requiring adaptive AAL solutions that help individuals to stay in their homes longer and maintain their independence [74]. Therefore, when developing new smart homes, it is crucial to consider how an individual's living environment can be developed, changed, and managed throughout their life [72]. This is particularly important as we aim to integrate smart home technologies that interact cohesively and systematically. For instance, a new build may initially be outfitted with physical structures suitable for a person without mobility issues, and these physical structures may influence the types of products in a home and the placement of devices and appliances. However, as the individual ages and their mobility needs change, they may require a mobility aid, thereby altering how they interact with their environment. Therefore, by understanding current needs and anticipating future needs, developers can create a flexible living environment that is adaptable and can be updated to suit an individual's evolving needs without requiring drastic infrastructural changes. A new build also provides the opportunity to establish backup systems for power and Internet to ensure continuity of services, which should be implemented accordingly.



"Aging is often accompanied by a decline in physical and cognitive function, requiring adaptive AAL solutions that help individuals to stay in their homes longer and maintain their independence."

Furthermore, many AAL technologies have been developed with the needs of various demographics in mind. However, their effectiveness is often hindered by a lack of acceptance among their intended population, including concerns about the technology's cost and usability, expected benefits, perceived need for technology, availability of alternatives, social influences, and specific characteristics of older adults [72]. Notably, older adults may feel indifferent toward or under-qualified to operate technology, which can hinder acceptance [72]. Although older adults' acceptance of technology can vary over time, it is necessary to consider the impact of smart technologies in their home environment at all stages [72]. When planning and initiating a new build, it's crucial to ensure that either the individuals living in the home or caregivers living outside of the home can confidently interact with and have control over the environment (i.e., the ability to modify features and actions or resolve technical errors with the devices or suites independently). Additionally, builders must consider ways to promote seamless connections to the network and other devices (e.g., by establishing manual connections, scanning to connect, pairing with devices or apps) and whether an older adult will be able to initiate and manage interactions with smart technologies independently.

It is important to remember that not only do the needs of older adults' change over time, but the state of technology itself also evolves—devices break, technologies and protocols become obsolete, and other technologies become more affordable or fashionable. Given that new builds require careful planning for the home's infrastructure to support technologies and determine their optimal placement within the home, flexibility to accommodate future changes must also be factored into planning. A crucial element of this planning is connectivity requirements, considering factors such as the positioning of devices when a wired connection is required. The connectivity needs may influence the placement of devices and determine whether items can be changed or repositioned within the home following installation. While it is valuable to conceal wires as much as possible to minimize clutter and safety issues, there should still be a degree of modifiability and serviceability. Specifically, it should not be impossible or unduly difficult to remove technologies, and components that require maintenance should not be inaccessible, although it may be desirable to have them discretely concealed when not needed.

Although there is a wide range of technologies suited to meet the specific needs of aging individuals, significant social, economic, and geographic challenges create inconsistent and inequitable access to assistive living technologies [75]. When constructing new buildings using smart home technologies, the geographic location and available resources may limit the compatibility of certain products and systems. The power needs of selected products and the power sources available to a building must be carefully considered, as different power sources can carry varying financial costs. Therefore, outfitting a home

with an elaborate smart home system may not be feasible in terms of power consumption or financial sustainability. Finally, network access must be considered depending on the connectivity requirements of the smart technologies. It is essential to assess whether a home has adequate network access to support the integration and functionality of the smart devices and systems.

6 Future Research Directions

In addition to the need for guidelines in the areas outlined above, we propose four future research projects that may significantly contribute to the development of guidelines for smart living environments for older adult care. The first proposed project, which is of immediate need, aims to develop specific, evidence-informed guidance on the design of environments. This includes establishing guidelines and checklists on factors such as the number and location of outlets or the ideal placement of monitoring devices. This work may be best addressed with a standard that is developed with the aid of a group of subject matter experts.

The second proposed project focuses on environmental sustainability. As evidenced by the smart home modelling exercise and the technology review above, many smart devices already have built-in energy-saving modes and consume less electricity than their older, non-IoT counterparts. Furthermore, some of the technologies reviewed for this report—particularly those categorized as "home environment monitoring and control" and "housekeeping"—are specifically designed to monitor and automate electricity, heating, and water usage to prevent unnecessary waste. Considering the ever-growing need to protect our planet and conserve natural resources, future projects to develop AAL-enabled homes and communities should aim to create not only smart living environments but sustainable smart living environments.

Table 1: Summary of key recommendations for smart living environments

Building Type	Recommendations
General	▪ Position devices to minimize added clutter and comply with accessibility guidance ▪ Maintain a field of view for sensor technologies ▪ Establish data-sharing strategies and pathways ▪ Consider interoperability and data security of devices ▪ Consider comparative data privacy protections of different device options and data management configurations ▪ Establish a periodic smart home modification plan
Retrofit	▪ Estimate overall cost of integrating AAL technologies beyond procurement (e.g., home infrastructure modifications, bandwidth) ▪ Reduce potential disruption to the residents' lives and displacement ▪ Maintain familiarity of the space ▪ Consider issues that may arise from integrating new technologies into existing networks
New Build	▪ Ensure environments are modular and adaptable ▪ Establish backup systems for power and i=Internet ▪ Allow for modifiability and serviceability of technologies ▪ Assess whether a home has adequate network access to support the integration and functionality of the smart devices and systems

The third proposed research project addresses the serviceability of smart living environments by older adults, their cohabitants, or informal caregivers. In our sample smart home modelling exercise, we explored the considerations involved in designing a smart living environment within a smart community for Grace, a fictional older adult. This case study described an older adult living in an urban or suburban community with consistent access to professionals who could assist in maintaining the smart home. However, this assumption may not apply to all older adults. For example, some may reside in underserved areas where professional assistance or community support are not readily available or they might be simply living farther away from their care partners and providers. Furthermore, many older adults may prefer to manage any issues themselves and maintain control over their environment, rather than relying on professionals for any modifications or troubleshooting. For this reason, it is essential to explore serviceability and find a balance between offering support and ensuring older adults can maintain an unobstructed and user-friendly smart living environment.

Lastly, the fourth proposed research project addresses the use of data from AAL devices and explores how data can be used in clinical and community care. Throughout this report, we were deliberately ambiguous regarding who collects and monitors the data from AAL and IoT devices to accommodate various use cases and community types. However, there is a clear need for guidance on how data may be effectively aggregated and interpreted for use in care. Such work may include developing standardized frameworks for data collection, storage, and analysis from smart living environments and explore how data can be securely shared and used to inform care decisions. Furthermore, regardless of the living environment, centralized data repositories managed by a central authority may be necessary to coordinate care. Establishing how this may be done safely and effectively is foundational to support the appropriate deployment of AAL.

7 Conclusions

This report aimed to provide guidance for community and technology developers interested in creating or retrofitting smart living environments that effectively support aging adults. This was achieved by exploring existing guidelines, modelling a sample smart home, and evaluating AAL technologies and trends. The guidance offered in this report must account for the evolving care needs of older adults across the continuum of care [3], [8], consider that many IoT technologies were initially designed as consumer products without the specific needs of older adults and/or persons with disabilities in mind [5], and prioritize establishing trust among older adults and their care partners regarding the safety and value of the AAL system [8], [9]. Nonetheless, investing in AAL systems may offer significant value, including enabling older adults to live in settings that are conducive to their preferred lifestyles [2], [11] and reducing health care expenses associated with LTC [12]-[15]. This report focused primarily on the building requirements of the smart living environments and examining the specific requirements of available AAL devices on the market.

The Canadian NBC [19] provides fundamental guidance for smart home and building design in Canada, focusing on resident safety and building integrity. Provincial and territorial building codes generally follow this guidance but may include additional requirements that consider local factors. This makes legislation at this level even more valuable to help address infrastructural and building needs in a smart home living environment. Despite the insights offered by academic and industry research on the most valuable components and requirements for creating smart living environments, as well as factors that have had limited technology deployment in the past, there is no comprehensive guidance on the deployment of AAL and smart technologies within living environments. This leaves room for further development in this rapidly evolving field.

The modelling of a sample smart one-bed-one-bath home within a retirement community (see Figure 2) demonstrated that the additional power cost of operating a smart home is negligible. The major expense arises from the costs of installation, maintenance, and infrastructural set-up associated with these technologies. This exercise also showed how decisions regarding the placement of technologies should be made, and therefore where infrastructure could provide support. It is recommended that a group of subject matter experts be assembled to formalize guidance and best practices for this in the future, potentially as a new standard. However, it should be noted that the use case for the model smart home describes an older adult with ample familial and community support who can assist in setting up and maintaining the smart home. We cannot assume that all older adults will have access to similar support networks, and additional measures may be required to service and maintain their smart home devices.

The evaluation of the technologies was conducted by gathering information from product pages, vendor websites, research articles, and product reviews. This approach aimed to identify the specific requirements of each technology in terms of power, Internet, internal network, water, sewer, mounting, HVAC, and gas. Among the types of technologies examined in this report, the most prevalent groups were those intended for remote patient monitoring and personal health monitoring. Conversely, devices facilitating fitness or housekeeping were less common. The consumer market is saturated with some types of smart and AAL devices, whereas other technologies present opportunities for growth. However, the availability of products is not necessarily informed by any evidence regarding the practical needs of older adults, and there is an opportunity to develop or refine technologies that more explicitly support their requirements and preferences. Future areas of AAL technology development that are expected to see increased interest include AI-driven lifestyle monitoring, interoperability, centralized data strategies, and ways to facilitate the inclusion of an older adult's circle of care with the aid of technology.

The technology review and exercises in this report led to some general-purpose recommendations, as well as recommendations for two different situations: retrofitting pre-existing homes into smart living environments and constructing new smart homes. General recommendations include avoiding clutter for safety and accessibility; maintaining a field of view for sensors and other technologies through means such as ceiling and corner mounting; considering secure interfacing of technologies; establishing data-sharing pathways; considering how data management can maintain resident privacy; and establishing plans to periodically re-examine and modify the smart home design. Retrofits offer the advantage of allowing older adults to remain in their preferred setting with familiar services and social contexts [2]. However, working with older structures and infrastructures poses unique challenges. These include addressing incompatibilities between smart technologies and existing building infrastructure, minimizing disruptions to residents' lives during the retrofit process, ensuring that the living environment remains familiar and comfortable, and considering issues that may arise from integrating new technologies into existing networks. New builds are valuable when the current living environment is no longer safe or suitable and alternative housing and care models are necessary to promote healthy aging [70].

Key considerations for new builds include planning for the adaptability of the living environment as the residents' needs and technology evolve, establishing backup systems for power and Internet to ensure service continuity, designing for serviceability, and accounting for the geographic location and resources of the home to identify compatible products and systems. Specific guidelines will support the integration of AAL technologies into older adults' living environments, facilitating the development of environments that prioritize feasibility and quality care. These guidelines will serve as valuable tools in designing and creating smart living environments that enhance the well-being and independence of older adults.

References

[1] Canadian Home Care Association, "Better Home Care in Canada: A National Action Plan," Canadian Home Care Association, 2016. [Online]. Available: https://cdnhomecare.ca/campaign-better-home-care-in-canada-a-national-action-plan/

[2] R. Turjamaa, A. Pehkonen, and M. Kangasniemi, "How smart homes are used to support older people: An integrative review," *Int. J. Older People Nurs.,* vol. 14, no. 4, Dec. 2019, https://doi.org/10.1111/opn.12260.

[3] C. Evashwick, "Creating the continuum of care.," *Health Matrix,* vol. 7, no. 1, pp. 30-9, 1989. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/10293297/

[4] A. Abdullah, R. Hamad, M. Abdulrahman, H. Moala, and S. Elkhediri, "Cybersecurity: A Review of Internet of Things (IoT) Security Issues, Challenges and Techniques," presented at the 2nd International Conference on Computer Applications & Information Security (ICCAIS), Riyadh, Saudi Arabia, May 1-3, 2019, pp. 1-6.

[5] S. Fattah, N.-M. Sung, I.-Y. Ahn, M. Ryu, and J. Yun, "Building IoT Services for Aging in Place Using Standard-Based IoT Platforms and Heterogeneous IoT Products," *Sensors,* vol. 17, no. 10, 2017, https://doi.org/10.3390/s17102311.

[6] Queen's University, "Assistive and adaptive technologies," Queen's Alumni Review, 2017. [Online]. Available: https://www.queensu.ca/alumnireview/articles/2017-05-25/assistive-and-adaptive-technologies

[7] Rob Goski, "Adaptive Vs Assistive Technology," Dakota Center for Independent Living. [Online]. Available: https://dakotacil.org/adaptive-vs-assistive-technology/#:~:text=Assistive%20technology%20refers%20to%20%E2%80%9Cany,that%20are%20specifically%20designed%20for

[8] G. Bin Noon, A. Shah, T. Hanjahanja-Phiri, L.X, Fadrique, and P.P. Morita, "Data Governance for Active Assisted Living Technologies Along the Continuum of Care," Canadian Standards Association, Toronto, ON, 2022. [Online]. Available: https://www.csagroup.org/article/research/data-governance-for-active-assisted-living-technologies-along-the-continuum-of-care/

[9] L. X. Fadrique, D. Rahman, and P. P. Morita, "The Active Assisted Living Landscape in Canada: Insights for Standards, Policies, and Governance," Canadian Standards Association, Toronto, ON, 2019. [Online]. Available: https://www.csagroup.org/wp-content/uploads/CSA-Group-Research-AAL.pdf

[10] Cogir Senior Living, "Retirement Home vs. Long Term Care – What's the Difference?" cogirseniorliving.ca. [Online]. Available: https://www.cogirseniorliving.ca/why-senior-living/long-term-care-vs-retirement-living/

[11] Canadian Institute for Health Information, "1 in 9 new long-term care residents potentially could have been cared for at home," Canadian Institute for Health Information, 2020. [Online]. Available: https://www.cihi.ca/en/1-in-9-new-long-term-care-residents-potentially-could-have-been-cared-for-at-home

[12] K. Wild, N. Sharma, N. Mattek, J. Karlawish, T. Riley, and J. Kaye, "Application of In-Home Monitoring Data to Transition Decisions in Continuing Care Retirement Communities: Usability Study," *J Med Internet Res,* vol. 23, no. 1, Jan. 2021, https://doi.org/10.2196/18806.

[13] D. R. Manis *et al.,* "Rates of health services use among residents of retirement homes in Ontario: a population-based cohort study," *CMAJ,* vol. 194, no. 21, pp. E730-E738, May 2022, https://doi.org/10.1503/cmaj.211883.

[14] D. V. Jeste *et al.,* "Age-Friendly Communities Initiative: Public Health Approach to Promoting Successful Aging," *Amer. J. of Geriatric Psychiatry,* vol. 24, no. 12, pp. 1158-1170, Dec. 2016, https://doi.org/10.1016/j.jagp.2016.07.021.

[15] A. J. Lehning, A. E. Scharlach, and J. K. Davitt, "Variations on the Village Model: An Emerging Typology of a Consumer-Driven Community-Based Initiative for Older Adults," *J. of Appl. Gerontology,* vol. 36, no. 2, pp. 234-246, Feb. 2017, https://doi.org/10.1177/0733464815584667.

[16] T. Tannou, T. Lihoreau, M. Gagnon-Roy, M. Grondin, and N. Bier, "Effectiveness of smart living environments to support older adults to age in place in their community: An umbrella review protocol," *BMJ Open,* Jan. 2022. https://doi.org/10.1136/bmjopen-2021-054235.

[17] M. Memon, S. Wagner, C. Pedersen, F. Beevi, and F. Hansen, "Ambient Assisted Living Healthcare Frameworks, Platforms, Standards, and Quality Attributes," *Sensors,* vol. 14, no. 3, pp. 4312-4341, Mar. 2014, https://doi.org/10.3390/s140304312.

[18] A. Oetomo, L. X. Fadrique, P. Amaral, A. Kuang, and P. P. Morita, "Zero-Effort, In-home Health Monitoring Using IoT Technology," Sidewalk Toronto Small Research Grant, Toronto, Canada, 2018.

[19] Canadian Commission, Building and Fire Codes, 2022, National Research Council of Canada, Ontario, Canada, 2020. [Online]. Available: https://nrc.canada.ca/en/certifications-evaluations-standards/codes-canada/codes-canada-publications/national-fire-code-canada-2020

[20] Government of Ontario, O. Reg. 332/12, *Building Code,* [Online]. Available: https://www.ontario.ca/laws/regulation/120332

[21] *Information and communication technology (ICT) code for buildings,* CSA EXP 100:22, Canadian Standards Association, Toronto, ON, 2022.

[22] *Medical Electrical Equipment – Part 1-11: General requirements for basic safety and essential performance – Collateral standard: Requirements for medical electrical equipment and medical electrical systems esed in the home healthcare environment,"* CSA-C22 No. 60601-1-11:11, Canadian Standards Association, Toronto, ON, 2011.

[23] T. Easty, B. Gentles, E. B. Sloane, and E. W. K. Wong, "Evaluating Best Practices and Gaps in Equipment and Medication Management in Home and Community Care Settings," Canadian Standards Association, Toronto, ON, 2022. Accessed: May 06, 2024. [Online]. Available: https://www.csagroup.org/wp-content/uploads/CSA-Group-Research-Equipment-and-Medication-Management-in-Home-and-Community-Care-Settings.pdf

[24] Cisco, "Cisco Digital Building Design Guide," 2017. Accessed: May 5, 2024. [Online]. Available: https://www.cisco.com/c/dam/en/us/solutions/collateral/workforce-experience/digital-building/digital-building-design-guidelines.pdf

[25] C. Zheng, J. Yuan, L. Zhu, Y. Zhang, and Q. Shao, "From digital to sustainable: A scientometric review of smart city literature between 1990 and 2019," *J. of Cleaner Production,* vol. 258, pp. 120689, Jun. 2020, https://doi.org/10.1016/j.jclepro.2020.120689.

[26] C. Ma, O. Guerra-Santin, and M. Mohammadi, "Smart home modification design strategies for ageing in place: a systematic review," *J. of Housing and the Built Environ.,* vol. 37, no. 2, pp. 625-651, Jun. 2022, https://doi.org/10.1007/s10901-021-09888-z.

[27] G. Cicirelli, R. Marani, A. Petitti, A. Milella, and T. D'orazio, "Ambient assisted living: A Review of Technologies, Methodologies and Future Perspectives for Healthy Aging of Population," *Sensors,* vol. 21, no. 10, May 2021, https://doi.org/10.3390/s21103549.

[28] *Accessible design for the built environment,* CSA B651-18, Canadian Standards Association, Toronto, ON, Canada, 2018. Accessed: Apr. 24, 2023. [Online]. Available: https://www.csagroup.org/wp-content/uploads/B651-18EN.pdf

[29] E. Tural, D. Lu, and D. Austin Cole, "Safely and Actively Aging in Place: Older Adults' Attitudes and Intentions Toward Smart Home Technologies," *Gerontology and Geriatric Med.,* vol. 7, 2021, https://doi.org/10.1177/23337214211017340.

[30] E. Gambi, L. Montanini, L. Raffaeli, and S. Spinsante, "Interoperability in IoT Infrastructures for enhanced living environments," presented at the IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom), Varna, Bulgaria, Jun. 6-9, 2016, https://doi.org/10.1109/BlackSeaCom.2016.7901573.

[31] National Institute on Aging, "A Good Night's Sleep." National Institute on Aging. https://www.nia.nih.gov/health/good-nights-sleep#:~:text=Older%20adults%20need%20about%20the,to%209%20hours%20each%20night (accessed Apr. 25, 2023).

[32] A. D. Christie, E. Seery, and J. A. Kent, "Physical activity, sleep quality, and self-reported fatigue across the adult lifespan," *Exp. Gerontology,* vol. 77, pp. 7-11, May 2016, https://doi.org/10.1016/j.exger.2016.02.001.

[33] M. D. Parkins *et al.,* "Wastewater-based surveillance as a tool for public health action: SARS-CoV-2 and beyond," *Amer. Soc. for Microbiology,* vol. 37, no. 1, Mar. 2024, https://doi.org/10.1128/cmr.00103-22.

[34] J. M. Goodman-Casanova *et al.,* "TV-based assistive integrated service to support European adults living with mild dementia or mild cognitive impairment (TV-AssistDem): study protocol for a multicentre randomized controlled trial," *BMC Geriatric,* vol. 19, no. 1, Sep. 2019, https://doi.org/10.1186/s12877-019-1267-z.

[35] A. Hernandez, F. Ibañez, and N. Atallah, "SENIORCHANNEL An Interactive Digital Television Channel for Promoting Entertainment and Social Interaction amongst Elderly People," presented at the International Workshop on Ambient Assisted Living, Torremolinos, Spain, Jun. 8-10, 2011, vol. 6693, pp. 137-142. https://doi.org/10.1007/978-3-642-21303-8_19.

[36] A. S. Billis, A. Batziakas, C. Bratsas, M. S. Tsatali, M. Karagianni, and P. D. Bamidis, "Enabling active and healthy ageing decision support systems with the smart collection of TV usage patterns," *Healthcare Technol. Lett.,* vol. 3, no. 1, pp. 46–50, Mar. 2016, https://doi.org/10.1049/htl.2015.0056.

[37] R. Thomson, J. L. Martin, and S. Sharples, "The psychosocial impact of home use medical devices on the lives of older people: A qualitative study," *BMC Health Service Res.,* vol. 13, no. 1, Nov. 2013, https://doi.org/10.1186/1472-6963-13-467.

[38] Government of Canada, "Technology Readiness Level (TRL) Assessment Tool," Government of Canada. 2021. [Online]. Available: https://ised-isde.canada.ca/site/clean-growth-hub/en/technology-readiness-level-trl-assessment-tool

[39] Accessibility Standards Canada, "A model standard for the built environment – accessibility," 2022. [Online]. Available: https://accessible.canada.ca/centre-of-expertise/built-environment#s2.6

[40] *Building construction — Accessibility and usability of the built environment,* ISO 21542:2021, International Organization for Standardization, 2021. [Online]. Available: https://www.iso.org/standard/71860.html

[41] *Accessible dwellings,* CSA/ASC B652:23, Canadian Standards Association Group, Toronto, ON, Canada, 2023. [Online]. Available: https://www.csagroup.org/wp-content/uploads/2430606.pdf

[42] V. Moudgil, K. Hewage, S. A. Hussain, and R. Sadiq, "Integration of IoT in building energy infrastructure: A critical review on challenges and solutions," *Elsevier.* Mar. 2023, https://doi.org/10.1016/j.rser.2022.113121.

[43] M. Jia, A. Komeily, Y. Wang, and R. S. Srinivasan, "Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications," *Automat. In Construction,* vol. 101, pp. 111-126, May 2019, https://doi.org/10.1016/j.autcon.2019.01.023.

[44] L. Gonçalves and L. Patrício, "From smart technologies to value cocreation and customer engagement with smart energy services," Energy Policy, vol. 170, pp. 113249, Nov. 2022, https://doi.org/10.1016/j.enpol.2022.113249.

[45] businesswire, "Canadian homeowners are eager to embrace smart home technology in the fight against climate change," businesswire. [Online]. Available: https://www.businesswire.com/news/home/20220421005734/en/Canadian-homeowners-are-eager-to-embrace-smart-home-technology-in-the-fight-against-climate-change

[46] B. Conde Gallego and J. Drexl, "IoT Connectivity Standards: How Adaptive is the Current SEP Regulatory Framework?," *IIC Int. Rev. of Intellectual Property and Competition Law,* vol. 50, no. 1, pp. 135-56, Jan. 2019, https://doi.org/10.1007/s40319-018-00774-w.

[47] M. Umair, M. A. Cheema, B. Afzal, and G. Shah, "Energy management of smart homes over fog-based IoT architecture," *Sustain. Comput.,* vol. 39, Sep. 2023, https://doi.org/10.1016/j.suscom.2023.100898.

[48] R. Turjamaa, A. Pehkonen, and M. Kangasniemi, "How smart homes are used to support older people: An integrative review," *Int. J. Older People Nursing,* vol. 14, no. 4, Dec. 2019, https://doi.org/10.1111/opn.12260.

[49] P. Liu *et al.,* "The effect of smart homes on older adults with chronic conditions: A systematic review and meta-analysis," *Geriatric Nursing,* vol. 40, no. 5, pp. 522-530, Sep. 2019, https://doi.org/10.1016/j.gerinurse.2019.03.016.

[50] J. Pattison Tuohy, "Matter: what you need to know," The Verge. https://www.theverge.com/23390726/matter-smart-home-faq-questions-answers (accessed Sep. 3, 2023).

[51] PATH. "About PATH," Path Platform. Accessed: Sep. 04, 2023. [Online]. Available: https://pathplatform.ca/about-path

[52] R. Jabbar, N. Fetais, M. Krichen, and K. Barkaoui, "Blockchain technology for healthcare: Enhancing shared electronic health record interoperability and integrity," presented at the IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT), Doha, Qatar, Feb. 2-5, 2020, https://doi.org/10.1109/ICIoT48696.2020.9089570.

[53] G. Dermody, R. Fritz, C. Glass, M. Dunham, and L. Whitehead, "Factors influencing community-dwelling older adults' readiness to adopt smart home technology: A qualitative exploratory study," *J of Advanced Nursing,* vol. 77, no. 12, pp. 4847-4861, Dec. 2021, https://doi.org/10.1111/jan.14996.

[54] N. Tcholtchev and I. Schieferdecker, "Sustainable and Reliable Information and Communication Technology for Resilient Smart Cities," *Smart Cities,* vol. 4, no. 1, pp. 156-176, Mar. 2021, https://doi.org/10.3390/smartcities4010009.

[55] P. Antonios, K. Konstantinos, and G. Christos, "A systematic review on semantic interoperability in the IoE-enabled smart cities," *Internet of Things,* vol. 22, pp. 100754, Jul. 2023, https://doi.org/10.1016/j.iot.2023.100754.

[56] Y. E. Osais, M. St-Hilaire, and F. R. Yu, "Directional Sensor Placement with Optimal Sensing Range, Field of View and Orientation," *Mobile Netw. and Appl.,* vol. 15, pp. 216-225, May 2009, https://doi.org/10.1007/s11036-009-0179-0.

[57] Government of Canada, "Innovation, Science, and Economic Development portfolio." Government of Canada. https://ised-isde.canada.ca/site/ised/en/about-us/our-organization/innovation-science-and-economic-development-portfolio (accessed May 21, 2023).

[58] Government of Canada, "The European Union's General Data Protection Regulation (GDPR)." Government of Canada. https://www.tradecommissioner.gc.ca/guides/gdpr-eu-rgpd.aspx?lang=eng (accessed May 21, 2023).

[59] European Commission, "Radio equipment directive (RED)." European Commission. https://single-market-economy.ec.europa.eu/sectors/electrical-and-electronic-engineering-industries-eei/radio-equipment-directive-red_en#:~:text=The%20radio%20equipment%20directive%202014,use%20of%20the%20radio%20spectrum (accessed May 21, 2023).

[60] A. R. Niemeijer, B. J. M. Frederiks, M. F. I. A. Depla, J. Legemaate, J. A. Eefsting, and C. M. P. M. Hertogh, "The ideal application of surveillance technology in residential care for people with dementia," *J. Med Ethics,* vol. 37, no. 5, pp. 303-310, May 2011, https://doi.org/10.1136/jme.2010.040774.

[61] L. X. Fadrique, "Privacy and Trust in Healthcare IoT Data Sharing: A Snapshot of the Users' Perspectives," MSc Thesis, School of Public Health Sci. Univ. of Waterloo. Waterloo, ON, Canada, 2019. Accessed: May 17, 2023. [Online]. Available: http://hdl.handle.net/10012/15333

[62] M. Mulvenna *et al.,* "Views of Caregivers on the Ethics of Assistive Technology Used for Home Surveillance of People Living with Dementia," Neuroethics, vol. 10, no. 2, pp. 255-266, Jul. 2017, https://doi.org/10.1007/s12152-017-9305-z.

[63] A. Arabo, I. Brown, and F. El-Moussa, "Privacy in the Age of Mobility and Smart Devices in Smart Homes," presented at the IEEE International Conference on Social Computing (SocialCom), Privacy, Security, Risk and Trust (PASSAT). Amsterdam, Netherlands, Sep. 3-5, 2012, https://doi.org/10.1109/SocialCom-PASSAT.2012.108.

[64] H. Lin and N. Bergmann, "IoT Privacy and Security Challenges for Smart Home Environments," *Inf.,* vol. 7, no. 3, p. 44, Jul. 2016, https://doi.org/10.3390/info7030044.

[65] S. Moncrieff, S. Venkatesh, and G. West, "Dynamic Privacy in a Smart House Environment," presented at the IEEE International Conference on Multimedia and Expo, Beijing, China, Jul. 2-5, 2007, https://doi.org/10.1109/ICME.2007.4285080.

[66] Y. Yao, J. R. Basdeo, S. Kaushik, and Y. Wang, "Defending My Castle," presented at the CHI Conference on Human Factors in Computing Systems, New York, NY, USA. July. 2-5, 2007. https://doi.org/10.1145/3290605.3300428.

[67] J. Bugeja, A. Jacobsson, and P. Davidson, "On Privacy and Security Challenges in Smart Connected Homes ," presented at the *Eur. Intell. and Secur. Inform. Conf.,* Uppsala, Sweden, Aug. 17-19, 2016, https://doi.org/10.1109/EISIC.2016.044.

[68] N. S. Channer, M. Hartt, and S. Biglieri, "Aging-in-place and the spatial distribution of older adult vulnerability in Canada," *Appl. Geography,* vol. 125, p. 102357, Dec. 2020, https://doi.org/10.1016/j.apgeog.2020.102357.

[69] H. Shellae Versey, S. Murad, P. Willems, and M. Sanni, "Beyond Housing: Perceptions of Indirect Displacement, Displacement Risk, and Aging Precarity as Challenges to Aging in Place in Gentrifying Cities," *Int. J. Environ. Res. Public Health,* vol. 16, no. 23, Dec. 2019, https://doi.org/10.3390/ijerph16234633.

[70] G. Spinelli, M. Micocci, W. Martin, and Y.-H. Wang, "From medical devices to everyday products: exploring cross-cultural perceptions of assistive technology," *Des. for Health,* vol. 3, no. 2, pp. 324-340, Jul. 2019, https://doi.org/10.1080/24735132.2019.1680065.

[71] D. B. Kaplan, T. C. Andersen, A. J. Lehning, and T. E. Perry, "Aging in Place vs. Relocation for Older Adults with Neurocognitive Disorder: Applications of Wiseman's Behavioral Model," *J Gerontology Social Work,* vol. 58, no. 5, pp. 521-538, Jul. 2015, https://doi.org/10.1080/01634372.2015.1052175.

[72] S. T. M. Peek, E. J. M. Wouters, J. van Hoof, K. G. Luijkx, H. R. Boeije, and H. J. M. Vrijhoef, "Factors influencing acceptance of technology for aging in place: A systematic review," *J. of Med. Inform.,* vol. 83, no. 4, pp. 235-248, Apr. 2014, https://doi.org/10.1016/j.ijmedinf.2014.01.004.

[73] S. Helal and C. N. Bull, "From Smart Homes to Smart-Ready Homes and cCommunities," *Dementia and Geriatric Cogn. Disorders,* vol. 47, no. 3, pp. 157-163, Jul. 2019, https://doi.org/10.1159/000497803.

[74] S. Abdi, A. Spann, J. Borilovic, L. de Witte, and M. Hawley, "Understanding the care and support needs of older people: a scoping review and categorisation using the WHO international classification of functioning, disability and health framework (ICF)," *BMC Geriatrics,* vol. 19, no. 1, p. 195, Dec. 2019, https://doi.org/10.1186/s12877-019-1189-9.

[75] C. A. Mattison, M. G. Wilson, R. H. Wang, and K. Waddell, "Enhancing Equitable Access to Assistive Technologies in Canada: Insights from Citizens and Stakeholders," *Can. J. on Aging,* vol. 39, no. 1, pp. 69-88, Mar. 2020, https://doi.org/10.1017/S0714980819000187.

Appendix A – List of Technologies

Table A: Summary of evaluated technologies with description of TRLs, applications, and requirements

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Arlo Pro 2 Smart Security Camera (VMC4030P)	Arlo	TRL-9	▪ Environment Monitoring ▪ Social Activity Monitoring	▪ Battery	Yes	▪ Wired ▪ Ethernet ▪ Wi-Fi	No	No	▪ Basic ▪ Suggested Mounting	No	No
Awair	Bitfinder	TRL-9	▪ Environment Monitoring	▪ NEMA 5 ▪ 100~240V AC, ▪ 50/60Hz USB-C ▪ 10W ▪ PoE enabled	Yes	▪ WiFi (2.4 GHz) ▪ Cellular ▪ Ethernet ▪ BACnet (MSTP/IP) ▪ Local API	No	No	▪ Specific Placement	No	No
Beddit 3 Sleep Monitor	Beddit / Apple	TRL-9	▪ Vital Sign Monitoring	▪ NEMA 5 2.5W	No	▪ Bluetooth 4.2	No	No	▪ Specific Placement	No	No
Body+	Withings (Nokia Health)	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	▪ Battery	Yes	▪ WiFi 802.11 b/g/n, Bluetooth	No	No	▪ Specific Placement	No	No
Dishwashers	Whirlpool	TRL-9	N/A	▪ NEMA 5 ▪ AC ▪ 120V ▪ 15-20A ▪ 60Hz	Yes	▪ Wi-Fi	Yes	Yes	▪ Involved	No	No
Echo Amazon Alexa	Amazon	TRL-9	▪ Social Activity Monitoring	▪ NEMA 5 ▪ 30W	Yes	▪ Bluetooth 4.1 ▪ Wi-Fi 5 (802.11ac) 2.4 GHz, 5 GHz	No	No	▪ Suggested Mounting	No	No
Ecobee4	Ecobee	TRL-9	▪ Environment Management	▪ NEMA 5 ▪ 3.5W ▪ Requires 5th wire for power ▪ (Optional power extender kit)	Yes	▪ Wi-Fi 2.4 GHz	No	No	▪ Basic ▪ Suggested Mounting	Yes	No
Fitbit Aria 2 (Smart Scale)	Fitbit	TRL-9	▪ Behavioural Change Management	▪ Battery	Yes	▪ Wi-Fi 802.11b/g/n, 2.4 GHz	No	No	▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Google Home	GTX Corp	TRL-8	▪ Social Activity Monitoring ▪ Environment Management ▪ Behavioural Change Management	▪ NEMA 5 ▪ 30W	Yes	▪ Wi-Fi 802.11ac (2.4GHz/5Ghz)	No	No	▪ Suggested Mounting	No	No
hugOne	Sevenhugs	TRL-9	▪ Environment Management ▪ Behavioural Change Management	▪ Battery	Yes	▪ Wi-Fi	No	No	▪ Suggested Mounting	No	No
Intelligent Bedsheet	Studio 1 Labs	TRL-5	▪ Vital Sign Monitoring ▪ Disease Management	▪ Unknown	Yes	▪ Wi-FI ▪ Wired	No	No	▪ Specific Placement	No	No
Liftware	Verily	TRL-9	▪ Disease Management	▪ Battery	No	▪ No	No	No	▪ Wearable	No	No
Microwave	Whirlpool	TRL-9	N/A	▪ NEMA 5 ▪ AC ▪ 60Hz ▪ 1100W	Yes	▪ Wi-Fi	No	No	▪ Basic	No	No
Nanoleaf Light Panels	Nanoleaf	TRL-9	▪ Environment Management	▪ NEMA 5 ▪ 100-120V ▪ 42W	Yes	▪ Wi-Fi	No	No	▪ Basic	No	No
Neato Botvac D7 Connected	Neato Robotics	TRL-9	▪ Environment Management	▪ Battery	Yes	▪ Wi-Fi, 2.4GHz, 5GHz	No	No	▪ Specific Placement	No	No
Nest Learning Thermostat	Nest	TRL-9	▪ Environment Management ▪ Behavioural Change Management	▪ Battery	Yes	▪ Wi-Fi 802.11b/g/n @ 2.4GHz, 5GHz, Wireless interconnect: 802.15.4 @ 2.4GHz, Bluetooth Low Energy (BLE)	No	No	▪ Basic ▪ Suggested Mounting	Yes	No
Nima Gluten Sensor	Nima	TRL-9	▪ Disease Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Nima Peanut Sensor	Nima	TRL-9	▪ Disease Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Proteus Discover	Proteus Digital Health	TRL-8	▪ Disease Management ▪ Vital Sign Monitoring ▪ Behavioural Change Management	N/A	No	▪ Bluetooth	No	No	▪ Wearable	No	No
ResearchKit	Apple	TRL-9	N/A	N/A	N/A	N/A	No	No	▪ Platform	No	No
Rf265beaesg (Refrigerator)	Samsung	TRL-9	▪ Social Activity Monitoring	▪ NEMA 14 ▪ 100W	Yes	▪ Wi-Fi ▪ Bluetooth	No	No	▪ Involved	No	No
S+ Sleep Sensor	Resmed	TRL-9	▪ Vital Signs Monitoring	▪ Battery	No	▪ Bluetooth	No	No	▪ Specific Placement	No	No
Sleep Tracker (Any Eight Mattress)	Eight	TRL-9	▪ Vital Signs Monitoring ▪ Disease Management ▪ Behavioural Change Management	▪ NEMA 14 ▪ 250W	Yes	▪ Wi-Fi 2.4GHz, 5GHz	No	No	▪ Specific Placement	No	No
Smart Indoor Air Quality Monitor/ Healthy Home Coach	Netatmo	TRL-9	▪ Environment Management	▪ NEMA 5 ▪ USB ▪ 4.5W	Yes	▪ Wi-Fi 802.11 b/g/n compatible (2.4GHz)	No	No	▪ Specific Placement	No	No
Smart Lock Pro + Connect	August	TRL-9	▪ Social Activity Monitoring ▪ Environment Monitoring	▪ NEMA 5 ▪ 2x AA batteries ▪ 12V wall unit	Yes	▪ Wi-Fi	No	No	▪ Basic	No	No
Smart Ranges (Stove)	Whirlpool	TRL-9	N/A	▪ NEMA 14 ▪ 220V	Yes	▪ Wi-Fi	No	No	▪ Involved	No	Yes/No
Smart Sensor System	Curiato	TRL-3	▪ Disease Management	▪ Unknown	Yes	N/A	No	No	▪ Specific Placement	No	No
Smart Wireless Pill Bottles	Adheretech	TRL-7	▪ Disease Management	▪ Battery	Yes	▪ Wi-Fi ▪ Bluetooth	No	No	▪ Wearable	No	No
Smartmat	Performance Research Inc	TRL-4	▪ Behavioural Change Management	▪ Unknown	No	▪ Bluetooth	No	No	▪ Specific Placement	No	No
Wall Ovens	Whirlpool	TRL-9	N/A	▪ NEMA 14 ▪ 220V	Yes	▪ Wi-Fi	No	No	▪ Involved	No	Yes/No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Washer and Dryer	Whirlpool	TRL-9		▪ NEMA 14 ▪ 220V	Yes	▪ Wi-Fi	Yes	Yes	▪ Involved	Yes/No	Yes/No
	Schneider Electric	TRL-9	▪ Environment Management	▪ Hardwired	No	N/A	No	No	▪ Involved	Yes	Yes
	Bosch	TRL-9	▪ Environment Management	▪ NEMA 5 ▪ NEMA 14 ▪ Combined	Yes	▪ Wi-Fi	No	No	▪ Involved	Yes/No	Yes/No
	Allen-Bradley (Rockwell)	TRL-9	▪ Environment Management	▪ Hardwired	No	▪ N/A	No	No	▪ Involved	No	No
G6 CGM	Dexcom	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	Yes	▪ Wi-Fi	No	No	▪ Wearable	No	No
Eversense	Senseonics	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Resideo	Honeywell	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	Yes	▪ Wi-Fi	No	No	▪ Wearable	No	No
Patient Monitoring	Philips	TRL-9	▪ Disease Management ▪ Behavioural Change Management	▪ NEMA 5 ▪ Combined	Yes	N/A	No	No	▪ Platform	No	No
ResMed	ResMed	TRL-9	▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	Yes	▪ N/A	No	No	▪ Specific Placement	No	No
VRI	VRI	TRL-9	▪ Disease Management	▪ Combined	Yes	▪ N/A	No	No	▪ Specific Placement	No	No
AliveCor	▪ KardiaMobile ▪ KardiaPro ▪ KardiaBand KardiaMobile 6L ▪ Veterinary Heart Monitor	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Combined	Yes	▪ Wi-Fi	No	No	▪ Wearable	No	No
ScienceSoft	ScienceSoft	TRL-9	▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Softeq	Softeq	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Wearable	No	No
Sleepace	Sleepace	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	No	▪ Bluetooth 4.0	No	No	▪ Specific Placement	No	No
Awair	Awair	TRL-9	▪ Environment Management	▪ NEMA 5 ▪ Battery ▪ Combined	Yes	▪ Wi-Fi 2.4ghz ▪ Bluetooth 4.1	No	No	▪ Specific Placement	No	No
Bosch	—	TRL-9	▪ Environment Management	▪ Hardwired	No	▪ N/A	No	No	▪ Basic	Yes	No
Vitls	Vitls	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management ▪ Behavioural Change Management	▪ Combined	Yes	▪ Wi-Fi	No	No	▪ Wearable	No	No
Neteera	Neteera	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ NEMA 5 ▪ Combined	Yes	▪ Wi-Fi	No	No	▪ Wearable	No	No
Cardiomo	Cardiomo	TRL-9	▪ Vital Sign Monitoring	▪ Battery	Yes	▪ Wi-Fi	No	No	▪ Wearable	No	No
Blumio	Blumio	TRL-9	▪ Vital Sign Monitoring	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
100Plus	100Plus	TRL-9	▪ Disease Management ▪ Behavioural Change Management	▪ Combined	No	No	No	No	▪ Platform	No	No
Encora Therapeutics	Encora Therapeutics	TRL-6	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	No	No	No	No	▪ Wearable	No	No
Neursantys	Neursantys	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	No	▪ Bluetooth Low Energy	No	No	▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
FlowSense	Rhaeos	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	Yes	▪ N/A	No	No	▪ Wearable	No	No
Sway	Sway	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	N/A	N/A	No	No	▪ Wearable	No	No
Vivalink	Vivalink	TRL-9	▪ Disease Management	▪ Battery ▪ Combined	No	▪ Bluetooth Low Energy	No	No	▪ Wearable	No	No
Pressac	Pressac	TRL-9	▪ Environment Monitoring	▪ Combined	No	▪ EnOcean	No	No	▪ Basic	Yes	No
Monnit	Monnit	TRL-9	▪ Behavioural Change Management ▪ Environment Monitoring	▪ NEMA 5 ▪ Battery ▪ Combined	No	▪ ISM 900MHz (902-928MHz) and 868MHz, 433MHz, and 940MHz radio bands	Yes	Yes	▪ Basic ▪ Suggested Mounting	Yes	Yes
Hospital at home	The Surgical Company	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
Tado	Tado	TRL-9	▪ Environment Monitoring	▪ Battery	Yes	▪ Wired ▪ Wi-Fi	No	No	▪ Basic ▪ Suggested Mounting	Yes	Yes
Rachio	Rachio	TRL-9	▪ Environment Monitoring	▪ Hardwired	Yes	▪ Wi-Fi	Yes	No	▪ Involved	No	No
Radiator Labs	Radiator Labs	TRL-9	▪ Environment Monitoring	▪ Unknown	Yes	▪ Wi-Fi	No	No	▪ Involved	Yes	Yes/No
Eco Frigo-Eco Term	ecoVent	TRL-9	▪ Environment Monitoring	▪ EU only	Yes	▪ Wi-Fi	No	No	▪ Involved	Yes	Yes
IOTAS	IOTAS	TRL-9	▪ Environment Monitoring	▪ Combined	Yes	▪ Wi-Fi	No	No	▪ Involved	Yes	Yes
Broadlink	Broadlink	TRL-9	▪ Environment Monitoring	▪ Combined	Yes	▪ Wi-Fi	No	No	▪ Involved	No	No
LifeSmart	LifeSmart	TRL-9	▪ Environment Monitoring	▪ NEMA 5 ▪ Battery ▪ Combined	Yes	N/A	Yes	Yes	▪ Basic	Yes	Yes
Orvibo	Orvibo	TRL-9	▪ Environment Monitoring	▪ Combined	Yes	N/A	No	No	▪ Involved	Yes	Yes

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Cielowigle	Cielowigle	TRL-9	▪ Environment Monitoring	▪ Hardwired	Yes	▪ Wi-Fi	No	No	▪ Basic	Yes	Yes
Accuhealth	Accuhealth	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management ▪ Behavioural Change Management	N/A	Yes	▪ 4G	No	No	▪ Platform	No	No
Agartee	Agartee	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
AllHealth CHOICE	AllHealth CHOICE	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform	No	No
Anelto Health	Anelto Health	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Wearable	No	No
AOJ Medical	AOJ Medical	TRL-9	▪ Vital Sign Monitoring	▪ Combined	N/A	N/A	No	No	▪ Platform	No	No
Biobeat	Biobeat	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
Biofourmis Care@Home	Biofourmis	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
Biotricity	Biotricity	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
TempTraq	Blue Spark Technologies	TRL-9	▪ Vital Sign Monitoring	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
BlueStar Telehealth	BlueStar Telehealth	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
CIRCUL Sleep & Fitness Ring	BodiMetrics	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
CareClix	CareClix	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
CareSimple	CareSimple	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Wearable ▪ Specific Placement ▪ Platform	No	No
Carium	Carium	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Cloud DX	Cloud DX	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Current Health	Current Health	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	N/A	N/A	No	No	▪ Wearable	No	No
Eko Health	Eko Health	TRL-9	▪ Vital Sign Monitoring	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
healthmote	healthmote	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
HealthSnap	HealthSnap	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
Health Wealth Safe	Health Wealth Safe	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Kencor Health	Kencor Health	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Life365	Life365	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Livongo	Livongo	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
Revup	MD Revolution	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Combined	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
MedM	MedM	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform ▪ Wearable ▪ Suggested Mounting ▪ Specific Placement	No	No
One Touch	One Touch	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	No	▪ Bluetooth	No	No	▪ Platform ▪ Wearable	No	No
PhysIQ	PhysIQ	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ None (Battery)	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Qardio	Qardio	TRL-9	▪ Vital Sign Monitoring	▪ Combined	No	▪ Bluetooth 4.0	No	No	▪ Wearable ▪ Specific Placement	No	No
Raziel Health	Raziel Health	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform ▪ Wearable ▪ Specific Placement	No	No
Remote Care Partners	Remote Care Partners	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Rimidi	Rimidi	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
Signallamp Health	Signallamp Health	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Smart Meter	Smart Meter	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Spire Health	Spire Health	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
Stel	Stel	TRL-9	▪ Vital Sign Monitoring	▪ NEMA 5	N/A	N/A	No	No	▪ Suggested Mounting ▪ Wearable	No	No
Validic	Validic	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
Vianova Health	Vianova Health	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management ▪ Environment Monitoring	N/A	N/A	N/A	No	No	▪ Platform	No	No
VitalTech	VitalTech	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
ViTel Net	ViTel Net	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Vivify	Vivify	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Combined	N/A	N/A	No	No	▪ Platform	No	No
VSee	VSee	TRL-9	▪ Disease Management	▪ Combined	N/A	N/A	No	No	▪ Platform	No	No
VyTrac	VyTrac	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Play-it Health	Play-it Health	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ NEMA 5 ▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
Ottalaus Health	Ottalaus Health	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Optimize Health	Optimize Health	TRL-9	▪ Disease Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
One Healthcare Solution	One Healthcare Solution	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform	No	No
Onduo	Onduo	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management ▪ Behavioural Change Management	N/A	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
Nonna Technologies	Nonna Technologies	TRL-9	▪ Vital Sign Monitoring	▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform ▪ Wearable ▪ Specific Placement	No	No
Cosinuss	Cosinuss	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable		
Cycplus	Cycplus	TRL-9	▪ Vital Sign Monitoring	▪ Battery	No		No	No	▪ Wearable	No	No
Misfit	Misfit	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Indie Health	Indie Health	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
Temp Pal	Temp Pal	TRL-9	▪ Vital Sign Monitoring	▪ Battery	Yes	▪ Bluetooth	No	No	▪ Wearable	No	No
J-Style	Jointcorp	TRL-9	▪ Vital Sign Monitoring ▪ Environment Monitoring	▪ Battery	Yes	N/A	No	No	▪ Wearable	No	No
Kingyield	Kingyield	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	Yes	N/A	No	No	▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
LEICKE	LEICKE	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth 4.0	No	No	▪ Wearable	No	No
Taiwan Biophotonic Co.	Taiwan Biophotonic Co.	TRL-9	▪ Vital Sign Monitoring	▪ Battery	Yes	N/A	No	No	▪ Wearable	No	No
Transtek	Transtek	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Viatom	Viatom	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management ▪ Behavioural Change Management	▪ Battery	Yes	N/A	No	No	▪ Wearable	No	No
TICKR	Wahoo	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth ▪ ANT+	No	No	▪ Wearable	No	No
Zephyr Technology	medtronic	TRL-9	▪ Vital Sign Monitoring	▪ NEMA 5 ▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
Zewa	Zewa	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
Sensoria	Sensoria	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Motiv Ring	Motiv	TRL-9	▪ Vital Sign Monitoring	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Moov	Moov	TRL-9	▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
Atlas Wearables	Atlas Wearables	TRL-9	▪ Vital Sign Monitoring	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Muse	InteraXon	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Ybrain	Ybrain	TRL-9	▪ Disease Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Fitbit	Fitbit	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Proteus	Proteus	TRL-9	▪ Disease Management	▪ Battery	Yes	N/A	No	No	▪ Wearable	No	No
Athos	Athos	TRL-9	▪ Vital Sign Monitoring	▪ Battery	No	N/A	No	No	▪ Wearable	No	No
Lively	Lively	TRL-9	▪ Behavioural Change Management	▪ Battery	Yes	▪ Cell Network	No	No	▪ Wearable	No	No
Whoop	Whoop	TRL-9	▪ Vital Sign Monitoring ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Silvertree	Silvertree	TRL-9	▪ Behavioural Change Management	▪ Combined	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
Human API	Human API	TRL-9	▪ Behavioural Change Management	N/A	N/A	N/A	No	No	▪ Platform	No	No
Ravean	Ravean	TRL-9	▪ Disease Management	▪ Battery ▪ USB charger	No	No	No	No	▪ Wearable	No	No
Cala Health	Cala Health	TRL-9	▪ Disease Management ▪ Behavioural Change Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Platform ▪ Wearable	No	No
QMedic	QMedic	TRL-9	▪ Disease Management	▪ Battery ▪ Combined	N/A	N/A	No	No	▪ Platform	No	No

Product Name	Vendor	Readiness	Application	Power	Internet	Internal network	Water	Sewer	Mounting	HVAC	Gas
One Drop	One Drop	TRL-9	▪ Vital Sign Monitoring ▪ Disease Management ▪ Behavioural Change Management	▪ Battery	N/A	N/A	No	No	▪ Platform ▪ Wearable	No	No
Strados	Strados	TRL-9	▪ Disease Management ▪ Vital Sign Monitoring	▪ Battery	No	▪ Bluetooth 4.0	No	No	▪ Wearable	No	No
Lief Therapeutics	Lief Therapeutics	TRL-9	▪ Disease Management ▪ Vital Sign Monitoring	▪ Battery	N/A	N/A	No	No	▪ Wearable	No	No
Goodrich International	Goodrich International	TRL-9	▪ Disease Management ▪ Vital Sign Monitoring	▪ Combined	N/A	N/A	No	No	▪ Wearable	No	No
SolitonReach	SolitonReach	TRL-9	▪ Disease Management	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Polso Watch	Chronisens ePolso	TRL-7	▪ Disease Management ▪ Vital Sign Monitoring	▪ Battery	No	▪ Bluetooth	No	No	▪ Wearable	No	No
Howz Home Care Kit	Howz	TRL-9	▪ Behavioural Change Management ▪ Environment Monitoring	▪ Hardwired	N/A	N/A	No	No	▪ Specific Placement ▪ Suggested Mounting	No	No
RX Pense Hub	Medipense	TRL-9	▪ Disease Management ▪ Behavioural Change Management	▪ NEMA 5 ▪ 120/240V ▪ 50/60Hz ▪ 3.0A max ▪ 12hr battery backup	Yes	▪ Wi-Fi	No	No	▪ Wearable	No	No
Monnit Water Leak Detector	Monnit	TRL-9	▪ Environment Monitoring	▪ Battery	Yes	▪ Wi-Fi ▪ Ethernet	Yes	No	▪ Basic	No	No
Pillcam	medtronic	TRL-9	▪ Disease Management	▪ Battery	No	N/A	No	No	▪ Wearable	No	No

Appendix B: Technology Evaluation

B.1 Physical

Mounting refers to the installation of sensors, devices, or suites that prepares a product for use. Mounting may involve setting, backing, or securing a product to the floor, wall, ceiling, or another surface. Water requirements involve all sources of water supply and output within the infrastructure of a home, including appliances. Sewerage is an implicit part of water requirements and refers to infrastructure that carries water and sewage (including "grey" or "black" water) out of the home and into receiving structures, which may be individual (i.e., a septic tank) or part of regional infrastructure. Fuels such as natural gas or propane are used to provide power in some homes and buildings and are primarily used for heating, cooking appliances, and electricity. Lastly, HVAC are integrated systems that control the temperature, humidity, and air quality in an enclosed space. When considering building requirements, it is necessary to consider the complexity and concealment of integrated systems and the intersection of various components.

Each technology was assessed for specific building requirements and categorized relative to its characteristics. For water and sewerage, items were categorized as either requiring integration or not requiring integration with these respective systems. Findings from the power evaluation are presented in Table A1. Similarly, items were classified as involving, not involving, or potentially involving HVAC, considering various product options available to consumers. These findings are presented in Table A2. Regarding gas requirements, also summarized in Table A2, products were grouped as requiring, not requiring, or potentially requiring gas as a power source. Lastly, mounting requirements, summarized in Table A3, were divided into no mounting required (i.e., the device can be placed on a surface or worn on the body, such as on the wrist, as an item of clothing, or as a pendant), basic mounting required (i.e., involving securing through simple and temporary changes, such as nails or mounting fixtures), and mounting required (i.e., requires infrastructural changes to or throughout the home).

Table B1: Number of technologies with building requirements for water and sewerage

	Requires integration	Does not require integration
Water	6	149
Sewerage	4	151

Table B2: Number of technologies with building requirements for HVAC and gas

	Requires integration	Does not require integration	May require integration
HVAC	13	140	140
Gas	8	142	5

Table B3: Number of technologies with building requirements for mounting

	No Mounting	Basic Mounting	Involved Mounting
Mounting	129	13	14

B.2 Electrical

Technologies were classified based on their power requirements, including NEMA 5 (National Electrical Manufacturers Association) connectors rated for 125 V maximum, NEMA 14 connectors rated for 250 V maximum, power over ethernet (POE), hardwired (devices that plug into an existing system with minimal power draw), and battery-operated (which may or may not be rechargeable). NEMA connectors are a type of power plug or connector made with specified electrical current ratings. A NEMA 5 connector supports common electrical devices, whereas a NEMA 14 connector is intended for larger appliances. Suites of devices with unique power sources, where information on individual devices is not publicly available, were classified as "combined". These suites were often a combination of NEMA 5 and battery. The category "unknown" was used for products where a prototype had not been developed, and "N/A" was used when a technology did not have a power draw of its own (e.g., data-sharing platforms). Findings from the power evaluation are presented in Table A4.

Table B4: Building requirements for power

	NEMA 5	NEMA 14	POE	Hardwired	Battery	Combined	Unknown	N/A
Number of products	28	6	1	6	80	43	4	28

B.3 Connectivity

While evaluating technologies based on connectivity, products were classified based on whether they require an Internet connection, do not require an Internet connection (i.e., where the sensors can still collect data and may transmit through other means), or are not applicable (i.e., data-sharing platforms or other Internet-based services exist). Findings from the power evaluation are presented in Table A5. Additionally, products were classified as having an internal network connection, not having an internal network, or having other connection options. Types of internal networks include Wi-Fi, Bluetooth, wired connections, cellular, and Bluetooth Low Energy (BLE). These are summarized in Table A6.

Table B5: Building requirements for Internet connectivity

	Requires Internet	Does not require Internet	N/A
Number of products	54	41	56

Table B6: Building requirements for internal network

	Wi-Fi	Bluetooth	Wired	Cell	BLE	Other	None
Number of products	39	38	5	3	3	3	3

CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.

CSA GROUP™

© 2024 Canadian Standards Association. All Rights Reserved.