

Concept Paper

The Convergence and Mainstreaming of Integrated Home Technologies for People with Disability

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Abstract: If human rights begin in small places close to home, technologies that enable people with disability to access and control their home environments are an important human rights instrument. Smart homes exemplify recent advances in design, building construction, and integration of technologies within the built environment. They draw on multiple social and technical disciplines that share a broad vision but lack a common language, creating ambiguity and limiting the usefulness of the evidence base in determining optimal ways to integrate technologies and housing design to meet diverse needs. The convergence of mainstream and assistive technologies offers the potential of accessible and affordable strategies for inclusion, but also risks further exclusion of marginalized sections of the population. Coordination of efforts might accelerate translation of knowledge and diffusion of innovations into the practices of planning, designing, building, and sustaining housing that promotes independent living. This conceptual paper reviews the theoretical frameworks and terminology from fields of research involved in the design and use of technologies in the home environment to enable people with disability and older people. It considers approaches to design and interventions that could inform policies and practices as well as further research and development activities.

Keywords: housing; smart home; technology; disability; assistive technology

1. Introduction

Where we live influences how we live. Ideas about the relationship between person and environment have emerged from various disciplines including ecology, developmental economics, human rights, and occupational therapy. Focusing upon a person's contexts as well as their personal capacities (or impairments) enacts a social relational view of disability. Human rights scholars draw the locus of attention outward from the individual to recognize the role of other factors in mediating disability [1]. The field of ecology provides the notion of personal competence and environmental press [2]. Developmental economics offers the human rights-based idea of the capability gap that arises when environments do not match a person's individual functioning or capabilities [3]. Transaction between a person, their environment, and occupation is a foundational tenet of occupational therapy, which directs us to attend to the environment as a critical facilitator of participation [4]. Our environments and our personal capabilities (including any variations in our human functioning) influence our ability to reach our human potential as expressed through occupational engagement [5]. These conceptualizations of environment are broadly congruent, and guide practices of assistive technology provision, including home design and modification for people with disability and people ageing into disability.

However, a closer look reveals discrepancies in language and assumptions that can be problematic in the context of a convergence of mainstream and specially designed products. A “lack of national and international consensus on terminology, classification or taxonomy of devices, products or service models” was noted in the Cochrane Review of smart home technologies within health and social care [6]. Without a shared understanding of assistive technology or other interventions, provisions to promote the rights of older people or people with disability may be interpreted narrowly as disability-specific devices and services, without consideration of the mainstream and emerging technologies that promote equality.

This paper discusses research and developments in technology interventions in home environments with the aim of identifying a shared language and scope for future work. It is informed by an extensive search of databases (Google, Pubmed, and Ebscohost) that identified any systematic and literature reviews of technology and environmental interventions for people with disability or older people published between 2000 and 2017. Search terms included DISABILITY (impairment, injury); AGE (older persons, elders); TECHNOLOGY (smart home/house, information/communication technolog*, telemonitoring, home automation, internet of things); ENVIRONMENT (ambient assisted living; residential care, supported living, nursing home, community resid*). It begins by exploring the perspectives underlying research into integrated home technologies, followed by a brief review of environmental interventions as part of rehabilitation, including common terms and definitions for assistive technology. The convergence of assistive technologies is discussed in the context of smart homes, followed by a call for a shared language and classification system to facilitate communication and promote interdisciplinary collaboration in future research and development.

2. Perspectives on Disability Underlying Research into Integrated Home Technologies

Standpoint theory has particular resonance in relation to disability [7] as the voices of people with disability are rarely present in the published research literature. The vantage point of researchers and authors is a powerful one [8]. Standpoint theory asserts that knowledge is always situated and influenced by the lens of the author [9], and that truth described from one vantage point is at best partial [10]. Insight into one’s own standpoint is a critical step in achieving epistemological justice, and can be gained, for example, by uncovering the lens of the professional [11], or by explicitly seeking alternative standpoints [12].

The different foci of fields using technology interventions in home environments should be considered in relation to the drivers of technology development in each case. Drivers in aged care practice include welfare expenditure concerns from governments and institutional care providers, leading to a focus on surveillance technologies for health monitoring and the automation of care [13]. Rehabilitation focuses upon the capability of specific rehabilitation technologies to compensate for functional disability but generally lacks an ecological view of the role of environment [14]. Informatics, telematics, and robotic research focus upon domotics or the application of technology in the home, a ‘technology led’ approach that features little discussion of the fit between technology and the end user, and even less consideration of users with functional diversity [15,16].

Discourse from the disability academy, that is, authors with disability writing about disability, emphasizes enhanced autonomy and a nuanced view of independence/interdependence as priority outcomes for users of assistive technology [17]. Contemporary efforts to design mainstream and assistive products have investigated widely disparate aspects and taken differing approaches to valued outcomes. With the widespread ratification of the United Nations Convention on the Rights of Persons with Disabilities (CRPD), recent philosophical and regulatory efforts have shifted toward person-focused approaches. Despite this, the voices and priorities of people with disability who are technology users are not central to assistive technology literature [18]. These observations point to the need for a conceptual review to promote knowledge and guide the development and evaluation of rehabilitation and inclusive development policies and practices in relation to housing and home

environments for people with disability. This begins by identifying a framework in which disability is understood in relation to technology and other environmental factors.

3. Framework for Understanding Functioning and Technology as Environmental Factors

There are a range of frameworks to describe the devices, infrastructure, systems, and environments incorporated into interventions to enable people with disability in their homes, for example [19,20]. The International Classification of Functioning, Disability and Health (ICF) has been widely adopted in research studies and mapped to policies and interventions, including those related to the CPRD [21].

The ICF emerged in response to longstanding debates between the disability academy and proponents of the medical model regarding the process of disability creation [22]. Developed by committees comprising a range of stakeholder standpoints, including those of disabled persons' organizations, the ICF set out to capture the role of personal and contextual factors alongside variations in body structure and function, and to identify human activity and participation [23]. Through this framework, the World Health Organization identifies a range of environmental factors, including the built environment, assistive products, and mainstream technologies, as well as services, systems, and policies that can both facilitate outcomes or create barriers. Dialogue is ongoing regarding whether the ICF has succeeded in its endeavor [24] and how it might be improved [25], but it remains a powerful and internationally utilized framework. Crucially, the ICF coding system enables a dualism in recognizing that barriers for one individual may in fact be facilitators for others (for example narrow walkways preventing a turning space for a power wheelchair user may facilitate wayfinding for a deafblind individual), and in comparing one's capacity in a standard environment to their performance in daily life. The next sections review rehabilitation and the incorporation of technologies and environmental modifications as part of assistive technology interventions.

4. Environmental Interventions as Part of Rehabilitation

Enabling environments are strongly linked to valued outcomes for people with disability such as autonomy, independence, and participation in a range of life tasks such as employment, community participation, leisure, and overall lifestyle [26,27]. A significant body of work also suggests the universally designed environments and products can enable function [28], and that adapting environmental contexts may be as effective an intervention as remediating an individual's functioning [29,30]. Communities and individual dwellings are, however, not generally designed with diverse users in mind [31]. In practice, accessible features are often included into housing builds on an ad hoc basis, with a 'retrofitting' process often needed to see what, if any, features are suitable for older people or people with disability [13,32].

Interventions that incorporate technology and environmental modifications to enable functioning are recognized as habilitation, rehabilitation, and assistive technology by the UN and WHO. Some scholars distinguish habilitation as meaning "to enable, or make able" from rehabilitation, meaning "to restore condition, operation or capacity", to highlight the often differing needs of people who acquire impairments through injury or illness compared to people born with impairment [33]. The WHO adopts rehabilitation as an umbrella term that is inclusive of both, defined as "a set of measures that assist individuals who experience, or are likely to experience, disability to achieve and maintain optimal functioning in interaction with their environments" [34]. The next section reviews some of the common terms and definitions for assistive technology interventions that fall under this umbrella term of rehabilitation.

5. Common Terms and Definitions for Assistive Technology

Assistive technology, as a subset of health technology, is a key rehabilitation intervention [35]. Health (or healthcare) technology is defined by the WHO as "the application of organized knowledge and skills in the form of devices, medicines, vaccines, procedures and systems developed to solve a health problem and improve quality of lives" [36]. Health technology includes medical, assistive,

and universally designed technologies. These all benefit people with health conditions, but assistive technologies are targeted at functional rather than medical outcomes. Compensation for functional deficits has been a focus of much assistive technology-related rehabilitation research and development, giving less emphasis to remediation of impairments [37].

A range of promising evidence exists linking assistive technologies to a range of outcomes including increased autonomy and independence, decreased risk, functional decline and admissions, consumer satisfaction and quality of life, and cost effectiveness [38]. Products and systems that enhance people's control over activities in their homes are proliferating, as are the range of terms that describe them. Table 1 provides a glossary of common terms and definitions identified from recent systematic and literature reviews on technology and environmental interventions for people with disability or older people.

Table 1. Common terms and definitions.

Assistive Technology (AT)	<p>"... inclusive of products, environmental modifications, services, and processes that enable access to and use of these products, specifically by persons with disabilities and older adults" [39] cited on page 3 of [40].</p> <p>Technology designed to be utilized in an assistive technology device or assistive technology service. Section 3(3) of the Assistive Technology Act) [41].</p>
Assistive Products (or AT Devices)	<p>Assistive products include especially produced or generally available devices, equipment, instruments, or software used by or for persons with disability</p> <ul style="list-style-type: none"> • for participation • to protect, support, train, measure, or substitute for body functions/structures and activities, or • to prevent impairments, activity limitations, or participation restrictions (ISO9999, 2016).
Assistive Technology Services	Any service that directly assists an individual with a disability in the selection, acquisition, or use of an assistive technology device [41].
Electronic Assistive Technology (EAT)	Refers to a broad range of devices. All electronic assistive technologies use information and communication technology (ICT) as a core component, generating dynamic, often intelligent devices capable of invoking a response following an action by a user. In addition, integration of a networked ICT infrastructure facilitates device communication, widening functional capability and capacity [6].
Information and Communications Technology (ICT)	Extended term for information technology (IT) that stresses the role of unified communications and the integration of telecommunications (telephone lines and wireless signals), computers, as well as necessary enterprise software, middleware, storage, and audio-visual systems, which enable users to access, store, transmit, and manipulate information [42].
Smart Home Technology (SHT)	<p>Any technology that automates a home-based activity [43].</p> <p>A smart home is viewed as a holistic and centrally controlled environment that enables interpretation of resident health needs and proactively responds to changes in health [44].</p> <p>Personal living spaces of older adults with embedded sensor technologies to promote independence and wellness are termed smart homes [45].</p> <p>Smart houses include devices that have automatic functions and systems that can be remotely controlled by the user to enhance comfort, energy saving, and security for the residents of the house [19].</p> <p>A residential setting equipped with a set of advanced electronics, sensors, and automated devices specifically designed for care delivery, remote monitoring, early detection of problems or emergency cases, and promotion of residential safety and quality of life [46].</p>
Smart Home and Ambient Assisted Living (SHAAL)	Systems utilize advanced and ubiquitous technologies, including sensors and other devices that are integrated in the residential infrastructure or are wearable, to capture data describing activities of daily living and health-related events [46].
Ambient Assisted Living	Use of information and communication technologies to augment the life environment and make it "smarter" (more adaptable, adaptive) for everybody [47].
Environmental Adaptations	Also termed home modifications or environmental interventions, refers to the alteration of aspects of environment(s) to facilitate access and outcomes for individuals and groups [26].

Table 1 is included to demonstrate the wide range of overlapping terms and concepts in current usage. It illustrates the contributions of various disciplines to research and development of integrated

home technologies, but also the challenges of comparing or combining data to inform policy or practice, particularly in the context of recent technological advances and trends.

6. Interconnectivity between Technologies and Environments

Terminology and definitions continually adjust in response to a convergence of technologies and to encompass future potentials. If assistive technology is a subset of health technology, then electronic assistive technologies represent a further subset of devices (and services) emerging from fifty years of engineering and telecommunication service development, and with a focus on automation of surveillance and care in the context of the aged care sector [13]. Similarly, Smart Home and Ambient Assisted Living (SHAAL) systems use sensor-based ubiquitous technologies, either wearable or integrated in the home infrastructure, to capture data describing activities of daily living and health related events.

A range of near-future technology developments include capacitive proximity sensing in smart environments [48] and assistance robots and service robots [49]. Integral to all these systems is machine-to-machine connection, described as the ‘internet of things’. This interconnectivity gives rise to the potential use of ‘big data’ for monitoring purposes in ways that are not yet conceptualized [46]. A necessary underpinning to the use of these technologies in housing is innovative builds. Future trends in building include building materials that enable signaling, localization, acoustics, and lighting technologies, and the development of multifunction building elements such as walls or ceilings that can integrate devices and their infrastructure [50].

7. Convergence of Assistive Technologies in Smart Homes

The last decade has seen mainstream smart home technologies pervade the open housing market. Ambient (built in) technology platforms or protocols that manage environmental context [16] are progressively replacing disability-specific electronic aids to daily living. This mainstreaming increases options for people with disability as smart home systems offer a greater range of functions, for example, roof windows automatically closing in case of rain and smart domestic appliances such as fridges that create shopping lists.

A convergence of mainstream and assistive technologies in the home context can be advantageous or marginalizing for people with disability. Many functions previously only available in assistive products are becoming mainstream, but many new mainstream products still lack functions that accommodate human diversity. For example, environmental control systems (ECS) were created specifically to cater to people with disability [51], but similar functions can now be found in general consumer products (e.g., Google Home, Amazon Echo) sold by large multi-national companies. However, these mainstream products have not been designed or evaluated in disability-specific research and development contexts, and lack of evidence for their use as rehabilitation interventions contributes to a delay in their adoption, recognition, and funding in health or disability services [52]. Convergence potentially addresses the aesthetic and design ‘lags’ that exist between disability-specific and mainstream technology [53].

Evidence suggests that many mainstream technology developments have been unhelpful for users with functional limitations. Products such as smartphones often feature complex controls and require extensive digital literacy to be configured and used by people with disability [52]. Technology-led design may miss the mark in terms of an understanding of user diversity [54,55]. In one example from the engineering literature, Zhang et al. investigated the impact of technology interfaces designed for ‘low’ and ‘high’ intelligence levels [56], determining that systems adapted to user diversity are more successful, and concluding user intelligence was an important factor to consider in system design. In this case, engagement with knowledge of brain injury and dementia and their cognitive sequelae in the system design may have been beneficial.

From a housing perspective, designing acceptable smart home technology requires an occupant needs analysis to inform design [57]. One review however commented that architects “usually consider

automation as a ‘necessary evil’” [50] and that decisions about technology are made for pragmatic reasons, for example, motion sensors are favored as they are independent from apartment infrastructure. There are demonstrable risks in technology-led design, which fails to comprehend the breadth of human diversity, and to gain collaborative input from representative users [43]. What is required is an overarching framework for technology within homes to guide designers and developers to be more inclusive.

8. Mainstreaming Inclusive Design

Given the trend toward convergence, the Association for Advancement of Assistive Technology in Europe (AAATE) has considered whether assistive products will disappear in future, due to the adoption of accessibility features in mainstream products [47]. AAATE acknowledges the “general trend towards a more inclusive society, where the living environment and mainstream products and services will include more features and capabilities that make them usable by a larger percentage of people with functional limitations” [47] (p. 10). Information and communication technologies (ICT), for example, will better support people with disability if they are designed to be:

- adaptable (configurable in such a way to tailor to individual user’s requirements)
- adaptive (automatically adapting to the user’s preferences),
- based on more flexible architectures (mobile and ubiquitous computing, with applications that can be downloaded from the “cloud”) [47] (p. 10).

However, even if mainstream products adopt the most advanced accessibility features, it is envisioned that a certain percentage of the population will always require specifically-designed assistive products [47].

9. Future Directions

For consumers, the future of accessible mainstream housing promises flexible technologies tailored to individuals that are seamlessly integrated into their homes. These technologies potentially enable people to self-manage their health, control their homes and household devices, and connect to services and the community [58]. To achieve this, the design, implementation, and evaluation of technologies within the home must consider a breadth of disciplines and discourses that contribute to the field, and adopt person-centered design thinking to interactions with technologies and the built environment at home.

Technologies and building principles and developments may emerge from, and be discussed in, widely differing literatures and sectors (see Figure 1). Contributions from a range of disciplines and standpoints must be sought out to contribute to a full picture of home environmental facilitators for people with disability.

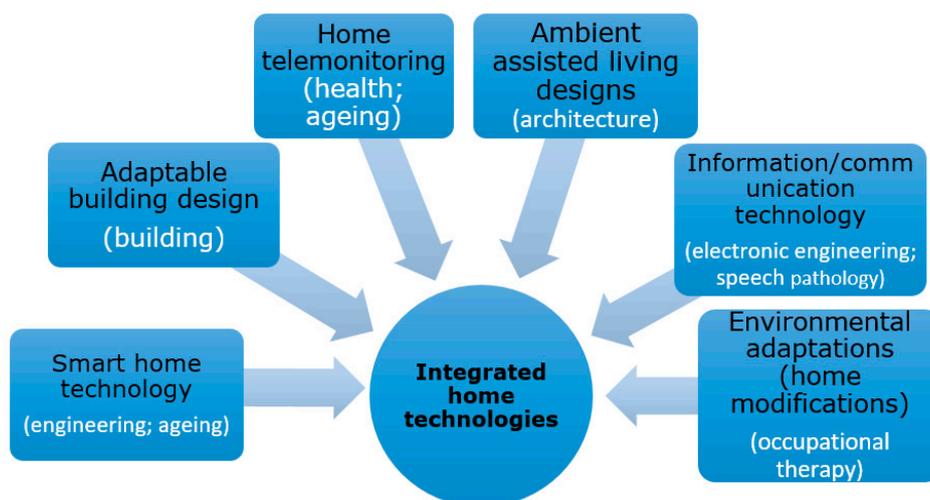


Figure 1. Disciplines and discourses related to integrated home technologies.

The relationship between assistive technology and the environment can be conceptualized as a technology chain or continuum whereby features in the environment strongly influence the need for, and effectiveness of, assistive technology [47]. In the case of smart homes, it is necessary to consider both the built environment and interfaces on products and features in the home with which residents interact.

The diagram depicted in Figure 2 is proposed as a heuristic approach to ensure any technology is considered from an integrated perspective, incorporating the build, assistive products, and individual user interfaces. Within this diagram, built features include infrastructure (hardwiring, smart home devices such as smart hubs), access features (circulation spaces and reach ranges), and fixtures (keyless entry; lever door openers). Assistive products may include computers, tablets and cognitive support software, monitoring and positioning systems, environment control units, and smartphones. User interfaces may be individually configured features of the assistive products, or may be additional elements, such as wireless smart buttons and proximity switches. Use of such a heuristic approach in assembling a solution will maximize ‘built potential’, that is, the potential of a thoughtful combination of these three elements to minimize the capability gap for people with disability.

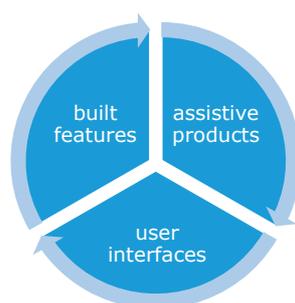


Figure 2. Three elements of integrated home technologies.

Consistent terminology is an essential in designing, describing, and reporting on integrated home technologies. When the person is the starting point for technology design, the person–technology interface (user interface) and the environment of use (home) come into focus, as well as technologies and devices to deliver the planned outcomes.

This paper has described diverse perspectives on the integration and use of technology in the homes of older people and people with disability. It acknowledges the dynamic context of ‘digital frictions’, where disability activism engages with and contests dominant assumptions driving research and development in this sector [59]. Given the rapid changes and technological advances, we advocate for the

adoption and use of internationally applicable classifications and terminology. International standards are coordinated by the International Organization for Standardization developed through a volunteer workforce of international member experts, inclusive of a range of stakeholders. The ingredients of integrated home technologies are addressed by the International Standard: Assistive Products for Persons with Disability (ISO 9999) which covers all assistive products, especially produced or generally available, for persons with disability [60]. ISO 9999 is revised every four years by international member experts, with public comment and balloting processes to capture feedback from diverse stakeholders. This dynamic and contemporary standard, adopted by many international jurisdictions to guide assistive technology provision, may provide the overarching framework and shared language required by these diverse bodies of enquiry.

10. Conclusions

‘Smart homes’ with connected technologies integrated into the building are increasingly utilized to support and enable people with disability. Currently, “ambiguity exists around how academics, service providers and service users categorize the integration and use of electronic assistive technology” [6]. This limits the usefulness of the evidence base in determining optimal ways to integrate technologies and housing design to meet diverse needs. An integrated, person-centered approach to the design of technology products and building ingredients is needed, alongside consideration of a breadth of disciplines that adopt different terms to describe goals and interventions. Further work is required to articulate the design and rehabilitative factors that match and adapt the technologies and home environments to meet individual needs and promote rights and inclusion. A shared language and classification system is a starting point for this work.

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