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Co-design to develop an Internet of Things Technology and Artificial Intelligence-based system to support older adults living independently.

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Abstract

Background: The number of older people with unmet health care and support needs is increasing substantially due to the challenges facing healthcare systems worldwide. There are potentially great benefits to using Internet of Things (IoT) coupled with Artificial Intelligence to support independent living and the measurement of health risks, thus improving quality of life for the older adult population. Taking a co-design approach has the potential to ensure that these technological solutions are developed to address specific user needs and requirements.

Objective: Using an adapted co-design framework, the aim of this study was to investigate stakeholder's perceptions of independent living and technology solutions, identify stakeholder's suggestions on how technology could assist older adults to live independently and explore the acceptability and usefulness of a prototype IoT solution to support independent living, "The NEX system".

Methods: Four phases were employed to design the NEX system as part of an Academic Industry Collaboration (AIC). Initially, a pre-design exploratory phase involved the recruitment of n=17 stakeholders using fictitious personas and scenarios to explore initial perceptions on independent living and technology solutions. Thematic analysis was applied to transcripts of these focus group discussions to highlight key themes. Subsequently, a co-design and testing phase involved an online survey (completed by n=380 stakeholders) and a prototype testing phase (completed by n=7 older adult participants) to obtain user needs and requirements relating to technology to support independent living and initial acceptability of a prototype system was completed. Lastly, as part of the post-design phase, workshops between the academic and industry partners were conducted whereby analysis of data collected from the pre- and co-design phases were discussed to inform recommendations for future system development.

Results: The pre-design phase revealed three broad themes: loneliness and technology, ageing and technology and adopting and using technology. The co-design phase highlighted key areas where technology could assist older adults to live independently: home security, falls and loneliness (older adult stakeholders), remote monitoring by family members (family caregiver stakeholders), communication with clients (healthcare professional stakeholders) and falls (homecare worker stakeholders). The prototype testing revealed that the acceptability aspects of the prototype varied across technology types. Ambient sensors and voice activated assistants were described as the most acceptable technology by participants. Lastly, the post-design analysis process highlighted that ambient sensors have potential for automatic detection of activities of daily living and also resulted in key recommendations for future developments and deployments in this area.

Conclusions: This research demonstrates the importance of considering multiple stakeholder opinions in development of solutions to support independent living. It also highlights the benefit of including a prototype testing phase in the process to provide valuable insight to the lived experiences of interacting with technology solutions in a home environment.

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Original Manuscript

Co-design to develop an Internet of Things Technology and Artificial Intelligence-based system to support older adults living independently.

Background

The world is witnessing a rapidly ageing population. Population ageing can be seen as one of the greatest successes of public health, as a longer life brings opportunities, not only for older people and their families, but also for societies as a whole (World Health Organisation, 2022). The extent of these opportunities and contributions however depends heavily on one factor: healthy and positive ageing (World Health Organisation, 2022). Therefore, mechanisms that support healthy and positive ageing are essential to ensure older people can enjoy physical and mental health and wellbeing to their full potential. Globally, health care policies including Ireland's "Slaintecare" (Government of Ireland, 2018) are focusing on extending the ability of older people to continue to live independently at home. This entails maintaining Quality of Life (QoL) as well as working to reduce the costs of an older person's care. Ageing in place has been defined as "the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level" (National Centre for Environmental Health, 2017). Research consistently shows that older people's preference is to "age in place" and to stay in their homes as they age (The Housing Agency, 2016; American Association for Retired People, 2022). In some cases this is driven by concerns over the cost of long term residential care, however research suggests that it is primarily due to a sense of attachment to their home surroundings, which is associated with social connectedness and improved wellbeing (Wiles *et al.*, 2012). This presents a grand challenge to ensure that older adults receive adequate and individualised care and support to maintain their health, well-being, and safety whilst living independently(Lewis and Buffel, 2020).

Internet of Things (IoT) technology and artificial intelligence (AI) have emerged as promising solutions to support older adults to live independently (Wang *et al.*, 2019). The IoT refers to the interconnectivity of devices and machines that enables the exchange of data and information. The integration of IoT technology and AI in the daily lives of older adults can potentially provide numerous benefits, including improved health monitoring, home safety, and social connection while improving health-related quality of life (HRQoL) (Tun et al., 2019). For instance, wearable IoT devices such as smartwatches and fitness trackers can monitor vital signs, including heart rate (Xiao et al., 2020), blood pressure (Carek *et al.*, 2017), and blood glucose levels (Rachim and Chung, 2019) and alert care providers in case of potential risk or abnormality. Similarly, smart home devices such as voice-activated assistants, smart thermostats and lighting systems can improve home safety by detecting and responding to hazards such as fires and intruders (Dahmen *et al.*, 2017). Additionally, AI-powered virtual assistants can provide companionship and social connection to older adults, helping to alleviate loneliness and depression (Corbett *et al.*, 2021). IoT technology and AI can also support older adults in managing chronic health conditions, such as diabetes, hypertension, and arthritis (Facchinetti *et al.*, 2023). It is important to consider the challenges and limitations to the use of IoT technology and AI in supporting older adults to live independently. Although there are numerous benefits to using technology to support ageing in place, one significant challenge is the potential privacy and security risks associated with the use of IoT devices (Jo, Ma and Cha, 2021; Wei *et al.*, 2023). Older adults may be vulnerable to identity theft, fraud, or other cybercrimes, and their personal health data could be at risk of unauthorised access or use. Innovators in this space need to be cognisant of how concerns relating to privacy may impact adoption of technology by stakeholders.

The NEX project is an Academic Industry Collaboration (AIC) aiming to develop an IoT coupled with AI solution to support older adults to live independently. Such a system could detect changes or irregularities in behaviour, possibly alerting caregivers to provide timely assistance. Despite the mounting evidence of the role of technology in supporting older adults to live independently at home (Baig *et al.*, 2019; Stavropoulos *et al.*, 2020; Tun et al., 2021) , evidence in the literature suggests that end user's acceptability and usability of technology is often neglected (Al-Shaqi et al., 2016) and the literature calls for a shift in emphasis from focusing on product design to the user perspective to redress this balance. The NEX team considers it is critically important that any proposed technology is aligned with core requirements. This underpins the focus of this paper; to co-design a citizen-centric system that blends user needs with technology advancement.

Methods

A user centred design approach (Pedrozo Campos Antunes *et al.*, 2019) was employed to identify user needs and requirements. This co-design approach focuses on partnering with end users to design technology with them and not for them. This paper describes the adapted use of a generative co-design framework for healthcare innovation (Bird *et al.*, 2021) to inform the design of the NEX system. This framework was designed to be adaptable and scalable by healthcare innovators and end-users seeking to change a specific healthcare process or system. The framework consists of three distinct phases: pre-design, co-design and post-design to inform the emerging technology system. The authors of this study provided transdisciplinary expertise and adapted this framework in a cohesive collaborative manner to incorporate prototype design testing as part of the co-design phase. This included the deployment of a prototype system design in the homes of end users to explore the feasibility of these technologies. Figure 1 illustrates the adapted framework used to co-design the NEX system.

Figure 1: Adapted transdisciplinary co-design framework for the NEX system

Pre-design

01 Exploratory workshops

The aim of the exploratory workshops was for older adult participants and family caregivers to reflect on independent living and to begin to explore how technology could assist them to maintain independence and provide care. Participants were recruited through Dublin City University Age Friendly network and advertising in local newspapers. Ethical approval for the UNR study was received from the DCU Research Ethics Committee in December 2019 (DCUREC/2019/223). Using a user-centred participatory co-design methodology, face-to-face workshops were conducted including the use of personas designed to be fictitious but authentic end users. This approach was considered appropriate to represent the participants or people like them in the study (Kohler *et al.*, 2017). Participants assisted in developing scenarios around the persona that captured a particular issue where technology could enhance self-management competencies or provide the support needed. The focus group conversations were audio recorded and the transcripts from the workshops were thematically analysed (Braun and Clarke, 2006). During this phase, a rapid review of the literature was conducted on how the use of IoT can support independent living in older adults.

Co-design and Testing

02 Online survey and co-design workshops

An online survey exploring the use of technology to support independent living in older adults was developed using LimeSurvey (Limesurvey GmbH). The NEX Public and Patient Involvement (PPI) advisory panel which consisted of older adults, health and social care professionals, family caregivers and home care support staff, assisted with the survey development and testing. This study received ethical approval from the DCU Research Ethics Committee (DCUREC/2019/223) and data collection commenced in June 2020 and continued until July 2020. The survey was advertised through the project's social media channels, Dublin City University Age Friendly University, Age Friendly coordinators in local councils nationwide and older adult and family caregiver community groups. Eligibility criteria included that respondents were either: older adults, living at home (age 60 years and older), family caregivers (caring for an older adult aged 60 years and older living at home) or health social care professionals (providing home support for older adults aged 60 years and older). Survey responses were exported to SPSS V25 and descriptive statistics and chi square analysis were applied to examine common attitudes amongst the respondents. An inductive thematic analysis was performed on free text responses from all stakeholder groups regarding scenarios where technology may assist with independent living.

Following on from the exploratory workshops and online survey, a user needs mapping exercise between the academic and industry partners was undertaken. This initiative focused on using the findings from prior phases concerning identified user needs and co-design criteria and mapping these to appropriate technological solutions. To investigate the values and concerns related to these identified technological solutions, online workshops were conducted to facilitate discussions centred on stakeholder's opinions on how specific types of technology could support independent living for older adults. Participants were recruited from those individuals who participated in the online survey and indicated their desire to engage with further research activity through the process of purposive sampling. Specific technology solutions (Voice activated assistant; ambient sensors; wearables; and an integrated system) were demonstrated to participants via Zoom. Online workshop transcripts were thematically analysed (Braun and Clarke, 2006).

03 Prototype development

The third phase of co-design involved testing of the prototype design arising from the findings of the workshops and survey. The findings from the online survey and online workshops were presented to the project industry partners, who were then tasked with designing a prototype system based on the user needs and co-design findings. The proposed prototype design consisted of contact sensors on entry and exit doors to the home and contact sensors on drawers and cupboards in the kitchen to detect activity around the house; smart plugs for kitchen appliances; 6-in-1 sensors to detect motion within rooms in the home alongside temperature, humidity, luminescence, UV light, and vibration; a Sony mWatch (smart watch device) as an alert system (call for assistance) and for measurement of sleep duration and step count; and an Amazon Echo Show 8 voice-activated assistant for entertainment/leisure use and reminder functionality. To explore the acceptability and technical performance of this prototype design, the prototype system was installed in the homes of 7 healthy older adults (aged ≥60 years) for 10 weeks. During this testing phase, data relating to experiences of the overall process (training, installation etc) was collected however for the purposes of this paper the findings described here are limited to those relating to the experience of each technology type. Prior to installation, a researcher completed a home configuration assessment with the participant by identifying the most appropriate locations to install NEX system technology. This testing phase occurred during COVID-19 pandemic restrictions resulting in technicians and researchers not being able to visit participants' homes for installation and training. To overcome this, participants were asked to self-install the prototype NEX system themselves with remote support. At the end of the testing phase, participants were supported to remove the technology from their homes. Participants also completed a process evaluation interview with a researcher via Zoom to discuss the acceptability of the overall system. These interviews were transcribed and thematic analysis was performed to identify key themes relating to the acceptability of the prototype NEX design.

Post-design

04 Analysis

This final stage of the design framework focused on considering the findings from the pre- and co-design phases in particular key user requirements, prototype design feedback and implementation considerations. Discussion workshops were conducted between the industry and academic partners wherein the academic partners presented the findings of the prototype testing and revisited the findings of the user needs and requirements activities. Both groups discussed solutions to the challenges faced during prototype testing whilst considering the user needs. These discussion workshops informed the development of a final specification document outlining the NEX system requirements (the functions the system must be able to perform), the data requirements (the types of information that a system must be able to process), and other requirements, including user support, guidance and training.

Results

01 Exploratory workshops

Workshops involving 17 participants (15 older adults aged 60 years and over and 2 family caregivers caring for an older adult aged 60 years and older living at home) were completed during March 2020. Three broad themes emerged from the thematic analysis of the transcripts from the exploratory workshops based on the aims: Loneliness and technology, Ageing and technology and Adopting and using technology.

Loneliness was a pervasive concern for older adults. This included issues with how loneliness routinely affects post retirement, and how this might lead to mental health concerns. Secondly, participants outlined understood the role of technology in facilitating independent living as related to older adults' dynamic ageing processes. This included identification of problems that arise with ageing, including the risk of falling, and possible solutions to address problems as they arise, including home safety and security. Thirdly, participants were concerned about how best to adopt and continue using technology in the longer term. A lack of familiarity with devices, the need for training, and a reluctance to use technology were key issues identified in the workshops in relation to adoption and use. Notably, participants explained the need to introduce technology gradually and build up skills over time. They indicated a positive benefit to using technology that is not stigmatising and that addresses their changing preferences and needs.

02 Online survey and online workshops

Online survey

In total, 380 respondents completed the entire survey (n=235 older adults, n=77 family caregivers, n=47 healthcare professionals and n=21 homecare support staff). The majority of the study population were female (80% n=303) with a total population mean age of 62.5 years (Standard Deviation 11.5 years). This was a well-educated sample, 58% (n=221) had completed third level education and 97% (n= 257) of older adult respondents reported that they frequently used a mobile/ smartphone device. The findings from the survey responses are reported elsewhere (Murphy et al., 2022). In brief, there was a high level of willingness reported across all groups (older adults 86% n=202, family caregivers 91% n=71, healthcare professionals 96% n=45 and homecare staff 76% n=16 to use technology in the future to support older adults to live independently. Additionally, the analysis highlighted that key areas identified by older adult stakeholders where technology could assist to live independently were: home security (33% n=77), falls (30% n=69), reduced mobility (23% n=55) and loneliness (23% n=54). Thematic analysis of free text responses for other stakeholder groups highlighted that there were differences in which technology could best assist with independent living. The key areas that were identified were: remote monitoring of family members (family caregivers), communication with clients (healthcare professionals) and falls (homecare workers). The main disadvantages were considered to be the ability of some older adults to use the technologies, limited access to broadband, impaired cognition limiting ability to use the technology and ability to interpret the data. Older adults perceived the main advantages of the technologies presented to be security/safety potential, use of these devices to provide independence and the ability to monitor their own health. Older adults reported the financial investment required and privacy concerns over data collected as the main disadvantages to these devices.

Online workshops

In total, n=29 participants (n=15 older adults, n=4 family caregivers, n=4 healthcare professionals and n=6 home support workers) took part in the online workshops where they discussed the potential value and concerns related to technology solutions identified by the technology partners. The findings are summarised in Table 1.

Table 1 Summary of technology types and participant value and concerns from the NEX online workshops

Technology	Older adults		Other stakeholders	
	Value	Concern	Value	Concern
Voice Activated Assistant	○Communication ○Entertainment ○Activity	○Dependency ○Privacy/intrusion ○Data security	○Reminders ○Social connections ○Entertainment ○Emergency calls ○Promote confidence	○Dependence ○Disembodied voice ○Annoying accent ○Issues for those with speech impediment
Ambient sensors	○Confidence ○Falls prevention ○Security ○Information for objective assessment	○Intrusion/tracking ○False alarms	○Fall prevention ○Home security ○Emergency response activation ○Clinical benefits ○Person-centred monitoring ○Value for carers	○Maintenance ○False alarms ○Data interpretation is complex ○Additional service required for monitoring and interpretation
Wearables	○Emergency response	○Stigma	○Fall detection	○Stigma

	○Falls detection ○Monitoring ○Sleep	○Forgetting	○Reassurance ○Rehabilitation ○Goal setting	○Range – geofencing ○Cumbersome ○Not aesthetically pleasing ○Interfere with daily activity ○May forget to wear
Overall system	○Reassurance ○Foster independence	○Trust ○Readiness ○Burden on family	○Favourable perception ○Substantial monitoring and information	○Ability to adapt to different contexts ○Ability to tailor system to individual need and preference

03 Prototype development

Seven healthy older adult participants were recruited to assist with the prototype testing whereby the prototype system was installed by participants themselves or a family member in their "Covid bubble" (due to Irish Government mandated Covid-19 restrictions on movement at the time) in their own homes for a duration of 10 weeks. For the purposes of this research, *healthy older adults* were defined as adults aged ≥60 years living independently with or without one or more stable chronic conditions. Participants (n=7) ranged from 63 to 87 years of age; 5 (71%) participants were women, and the remaining 2 (29%) were men. All participants were living alone in Ireland (6 living in urban locations) and 1 living in a rural location. The majority of participants (6/7, 86%) described their health as "very good" or "excellent," and 86% (6/7) of participants reported having one or more chronic illnesses. All participants reported regular use of a smartphone, indicated some level of familiarity with technology, and had a home broadband connection. At the end of the 10-week testing phase, participants completed an evaluation interview of the prototype testing. Participants were asked to comment separately about their experience of the ambient sensors, and of using the voice activated assistant and wearable device. The most salient findings from the thematic analysis of transcribed interviews in relation to users' experiences of each component of the NEX system are outlined below.

Wearable device

The Sony mWatch (smart watch device) was selected by the technology partner for this testing phase due the ability to raise an emergency alert and link with satellite and store locations and track GPS (in emergency alert situation only). Most participants were underwhelmed or disappointed by the Sony mWatch. A number of the participants already owned a Fitbit and, in the interviews, they compared the aesthetics and functions of the smart watch with their Fitbit and concluded that the smart watch was the less attractive option. Aesthetically, the smart watch was described as too big, chunky, awkward and masculine looking (in the case of two female participants).

I didn't like the watch, I didn't like the style, it wasn't a bit feminine. (FTO1)

It was awkward to wear and got in the way of normal everyday activities. One participant remarked on the frequency with which the battery ran down and she had to charge the watch, comparing it unfavourably to the longer battery life of her Fitbit (FT01). Two participants (FT02, FT04) also pointed out that they would like to have a history of previous step counts on the watch but that the watch did not provide this. Therefore, an important benchmark by which they could judge whether their physical activity was increasing or not over time was not available to them.

> *I've seen watches that would give you yesterday's and today's steps but there was no history on this watch. (FT04)*

Voice activated assistant

The Amazon Echo 8 (Alexa) was selected by the technology partners for prototype testing. All seven participants reported that they could see the benefits that the Amazon Echo offered or could offer, although two participants (FT03, FT04) said they found the Amazon Echo "gimmicky" and hence would not be of much interest to them now that the testing phase was over. Those participants who described liking the Amazon Echo were very enthusiastic about some core features, namely Alexa's ability to tune into international radio stations, to play any type of music, to provide the weather forecast on demand and to assist with shopping by recording a shopping list. Three of the participants appreciated the sense of company that the presence and voice of Alexa gave them.

> *I felt it was a bit of company, to have a voice coming back at you…you could have a conversation with it...I just think it's a wonderful piece of equipment. I live on my own. (FT01)*

> *If I was lonely, it was quite nice to have someone to talk to and who wouldn't get cross with you (FT03)*

Regarding privacy concerns, two participants (FT03, FT04) reported they turned off the camera on the Amazon Echo. Three of the participants were wary of Amazon as a company (FT02, FT04, FT07). One participant talked about not wanting Amazon to have access to her personal details so she chose not to download anything additional. Another participant enjoyed Alexa but stated they intended to get a Google Nest instead (FT02). Another participant explained:

> *You have to sign up for certain services. For that reason, I was reluctant to ask much of Alexa. I didn't want to be charged for something I didn't want (FT04)*

Ambient sensors

The ambient sensors were very well-tolerated by all participants once they had been installed. All participants forgot about the sensors after an initial period, and did not feel self-conscious as they completed their daily activities. Some participants commented that they were reminded that they were being monitored when they saw a green flashing light from the 6-in-1 sensor.

> *I forgot all about them, except occasionally I might notice the green light flashing if I opened the door (FT01)*

When asked whether they had changed their behaviours or routines in any way as a consequence of knowing their activities were being monitored, none of the participants believed they had changed anything about their behaviours. There was an appreciation for the capability of the sensors to provide a sense of security or comfort through monitoring without being intrusive, as highlighted by one participant:

…. great to be able to know what state people are in and what they are doing without necessarily a camera being on them (FT03)

Analysis

To consider the implications of the co-design process on the final NEX system design, discussion workshops between the NEX team members (academic and industry project partners) were conducted. The discussion workshops were based on a) the findings of the pre- and co design phases, and b) an investigation of the technical performance of the system during prototype testing. The results of the investigation of the technical performance of the system highlighted key issues that impacted on participant's experience of the NEX system and its technical performance. Regarding the participant's experience of the prototype during testing, at the point of installation, one participant withdrew from the study citing the participant-led installation as the reason. Considering the potential impact of the self-installation process on participant retention, for subsequent deployment it is recommended that the NEX system should be installed in each participant's home by a technical expert based on the personalised routines and preferences of the participant. Additionally, it was recommended, based on the feedback from the process evaluation, that the Sony mWatch would be discontinued for future deployments and that step and sleep data should be collected via an alternative wearable device which can provide data feedback summaries to participants and caregivers.

The industry partners assessed the technical performance of the NEX system by analysing aspects of front-end usability (examining number of system crashes, etc) and back-end issues (e.g., memory use and database integrity) the results of which highlighted issues relating to battery life, configuration of sensors, use of the smart watch and missing data. The missing data was attributed to issues relating to battery life, participant-led installation of devices and to devices being switched off for periods of time. To overcome this issue in the future the industry partner will implement automatic system data checks in future deployments to eliminate/reduce data losses. For future trials, it was decided that a review of the sensors used was required and it was necessary to consider next generation devices with longer battery life. With regards to configuration settings, it was decided that only pre-tested Smart Plugs will be used as part of the NEX system install. Lastly, to improve the accuracy of ADL detection in the future deployments, based on data analytics, it was decided that a larger range of sensors and smart plugs should be deployed alongside more frequent ground truth data collection from participants to assist with annotation and the extraction of rules.

Discussion

The results of this research have implications for researchers, practitioners and digital health organisations who are aiming to design and implement technology-based solutions for healthcare. The co-design process employed in this research facilitated the consideration of the needs and requirements of the proposed NEX system through a dynamic design process and design tool selection in response to a multitude of stakeholder perspectives.

Principal Results

The pre-design exploratory workshops highlighted important viewpoints on independent living and technology solutions which contributed to the design of the NEX system. The application of technology to support a healthy lifestyle and safety at home was raised by participants. A recent scoping review by Hamid *et al.*, suggests that technologies such as robotics, virtual reality, wearables, artificial intelligence and smart textiles may be key vehicles to promoting healthy lifestyle behaviour amongst older adults in the future. One area where technology has made significant advancements is in promoting physical activity and exercise among older adults (Sohaib Aslam *et al.*, 2020). Additionally, efforts using smart home technology have been shown to support older adults in maintaining their safety. For example, wearable devices such as personal emergency response systems and fall detection devices can provide older adults with a sense of security and help them to live independently for longer (Tun et al., 2021). In terms of the NEX system prototype testing, a smartwatch device with step count motivation (to promote healthy lifestyle) and emergency response features (to address safety support) was identified to meet the user needs and requirements. Whilst the particular smart watch device was not deemed acceptable mainly due to aesthetic properties, there were also technical issues with the Global Positioning System (GPS) emergency response feature which made this feature redundant in this context. Participants did report to like the step count motivation feature and so alternative solutions to this will be further explored in future trials.

Interestingly, in the prototype testing, of all of the different technology types that make up the NEX system, ambient sensors were the most widely accepted technology amongst participants. Additionally, ambient sensors collected the most valuable data to assist with automated identification of activities of daily living (Timon *et al.*, 2023) which has been implicated as an important approach for supporting continued autonomous living for older adults in the future (Camp *et al.*, 2020). It is worth noting that when presented with new technology, as was observed in this prototype study, research participants present high levels of engagement, but over time, the users start losing interest (Ollevier *et al.*, 2020). This has been evidenced by others(Jeno *et al.*, 2019; Shin *et al.*, 2019) that have investigated motivation amongst long term use of assistive technology. As part of the NEX project, the authors explored the intentions of older adults to adopt and use smart home technologies using the Theoretical Domains Framework (TDF), the results of which are reported elsewhere (Kilcullen *et al.*, 2022). This work highlighted that unless methods to increase intrinsic motivation are considered in the design of such systems, long-term adherence is unlikely to be achieved. This is an important point of consideration for future research to promote consistent engagement by participants for the collection of data to support their wellbeing.

Barriers and facilitators to co-designing technology to support independent living

A systematic review of co-designing technology for aging in place (Sumner *et al.*, 2021) highlights the many benefits to involving stakeholders in developing technology solutions for older adults including improved acceptance and adoption. However, this review also highlighted that one of the issues to co-designing in this context was that a lack of knowledge could cause unrealistic expectations and hinder the design process. This presents a potential barrier in the co-design technological solutions with older adults, some of whom may be unfamiliar with the functionality of smart devices. In the co-design of HABITAT: An IoT Solution for Independent Elderly, (Borelli *et al.*,

2019) conducted in person co-design workshops in day centres where older adult participants could interact with smart devices and through the support from research team, develop knowledge relating to functionality. This issue was also considered as part of the NEX co-design process however due to Coivd-19 constraints, at the early co-design stages (online focus groups and surveys) participants were not able to interact with some of the proposed technological solutions. To overcome this, demonstration videos were developed to showcase each of the potential technology solutions and their functionality. The videos were embeded in the survey to assist with responses relating to the usefulness of technology and were also played via online focus groups to aid discussions. Participants from the pre-design phase in this also discussed the need for training and support to develop digital literacy skills required to adopt technology to support independent living. Jiménez *et al.*, (2021) outlines the benefits of an iterative training approach for supporting older adults in the development of these skills. This approach involves a continuous process of training and support, allowing older adults to gradually build their digital literacy skills and confidence in using technology. This approach was subsequently implemented as part of the action research cycle which explored the feasibility and acceptability of NEX in a larger population of community dwelling older adults.

Academic-industry collaboration

Academic-industry collaboration (AIC) offers a mechanism to bring sectors together to alleviate the challenges of using technology to support healthcare such as engagement, sustainability, dissemination, evaluation, and equity (Ford *et al.*, 2021). The literature highlights several barriers to AIC including time stand point, knowledge development and the commercialization and/or protection of intellectual property, but also lists many facilitators such as starting with smaller projects and excellent communication channels (Rossoni et al., 2023). For the NEX project team, clear, efficient and regular communication channels between the academic and industry partners were vital for building strong relationships, fostering collaboration, and driving productivity. Weekly meetings between project managers from both the academic and industry partners facilitated an agile working process. Additionally, the co-design process facilitated the integration of stakeholders needs and requirements from the inception of the project. This was another factor that contributed to the success of the NEX system design as Baines et al. noted that public patient involvement in digital health innovation is largely viewed as valuable and essential, but rarely practised (Baines *et al.*, 2022). Lastly, regular discussion workshops between the academic and industry partners, where team members and key decision makers came together to review co-design findings and decide on solutions and future direction, was another important contributor to the success of this collaboration.

Limitations

As for many other research projects, the COVID-19 pandemic and subsequent restrictions on movement limited the way the research teams could engage with participants and may have had implications for both co-design and prototype testing in this study. For aspects of the co-design process, focus groups were conducted online using Zoom as it was not possible to meet in person due to national Covid-19 guidelines. It is possible that richer discussions and opinions on how individual technology types may support independent living might have been achieved during in person focus groups. Additionally, the protype testing of NEX occurred during a time when restrictions on movement were in place and therefore the technician could not install the prototype in the homes of participants. Although participants self-installed the technology with the remote support of a technician, there were instances where technology failed (due to battery life etc.) and data was lost, impacting the assessment of the technical performance of NEX. However, these adapted research approaches did facilitate the progression of this research during difficult circumstances.

Conclusion

The approach of incorporating prototype testing into the co-design process, as described by the authors, enabled the project team to use an agile approach and consider a multitude of stakeholders' opinions in the design of this system. Although Covid-19 restrictions prevented face to face co-design research activities, the research team adapted research methods to facilitate online data collection and remote real-life testing. In terms of the research methodology, the authors presented an approach for a more comprehensive co-design process involving older adults experiencing technology to support independent living in the real context rather than conducting experiments and analysing results based on a limited exposure and assessment. The findings from this co-design process highlight that early participant engagement in the design process is necessary to ensure that the system meets the needs of stakeholders, which in turn supports technology adoption and cultivates motivation to use technology. An appreciation of the role of co-design and stakeholder opinions in terms of user needs and requirements by industry partners and clear and frequent communication channels were key attributes to a successful academic-industry collaboration in the area of digital health innovation.

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Conflict of interest

None declared

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Supplementary Files

Figures

An adapted transdisciplinary co-design framework.