Co-designing technology for ageing in place: A systematic review

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Abstract

Background: Co-design in healthcare has become mainstream. Co-design with end-users can improve patient satisfaction, outcomes and reduce the cost of care. As populations age, there is a growing interest to involve the elderly in the co-design of health technology to maintain their well-being and independence. However, it is less clear if co-designed technology improves health and well-being outcomes. The aim of this study is to evaluate co-designed technology that supports elders to age in place.

Methods: We conducted a systematic review to: i) investigate the health and well-being outcomes of co-designed technology for elders (≥ 60 years); ii) to identify co-design approaches and contexts where they are applied and; iii) to identify barriers and facilitators of the co-design process with elders. Searches were conducted in MEDLINE, EMBASE, CINAHL, Science Citation Index (Web of Science), Scopus, OpenGrey and Business Source Premiere databases using MeSH terms and key words.

Results: We identified 14,649 articles of which 34 studies were included. Studies were from Europe (n=28), Australia (n=4), America (n=1) and Canada (n=1). Twenty of the 32 studies targeted older adults (≥ 60 years old) and 14 targeted specific medical conditions or elder-related issues. Technological solutions included robots, online applications and software, smart televisions, computer games for exercise, global positioning solutions, smart home systems and design of care pathways. Five studies reported health and well-being outcomes and were extracted. The health and well-being impact of co-designed technology was inconsistent. Co-design processes varied greatly and in their intensity of elder involvement. Common facilitators of and barriers to the co-design process included the building of relationships between stakeholders, stakeholder knowledge of problems and solutions, as well as expertise in the co-design methodology.

Conclusions: The co-design approach was applied in the design of a diverse set of technologies. The effect of co-designed technology on health and well-being was rarely studied and it was difficult to ascertain its impact. Future co-design efforts need to address barriers unique to the elderly population. More evaluation of the impact of co-designed technologies' is needed and standardisation of the definition of co-design would be helpful to researchers and designers.

Background

The desire to remain independent and live at home or within an individual's community is increasingly recognised as the preferred living arrangement among the elderly (1–3). Governments and international agencies have conceptualised the preference to age in the community as 'ageing in place'. The United States Center for Disease Control and Prevention defined the term as "the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income or ability level" (4). Policies and initiatives supporting successful and independent ageing have increased in many countries (5–9). These policies preserve elderly's independence through infrastructure development, urban planning, developing community-based resources and the deployment of technologies (10–13). However, elders living in the community are more prone to suboptimal management of chronic diseases, encounter accidents, experience social isolation and depression (14). Technological solutions have emerged to address these challenges to create a safer environment for active ageing.

The range of elder-targeted technology is diverse. They include tele-communication systems (15), health monitoring devices (16), social and assistive robots (17, 18) and 'smart home' systems (19–21). However, the implementation of these technological solutions has been met with resistance and underuse (22). One explanation for poor uptake is the limited or the complete lack of end-user involvement in technology development. The development process is often led by technologists and healthcare professionals; end-user views and preferences have traditionally not been taken into account. End-users concerns could include the usability, usefulness and adaptability of technology, cost to end-user, personal security, and threat to individual's identity and independence (22–24). To address these concerns, participatory approaches have grown, such as the co-design process (25–27).

The definition of co-design varies greatly. Osborne et al. defines co-design as "the voluntary or involuntary involvement of public service users in any of the design, management, delivery and/or evaluation of public services" (28). The Western Australia Council of Social Service sums up co-design as "collaboratively designing services with service-users, service-deliverers and service-procurers" (29). Another definition from The Point of Care Foundation states "experience-based co-design (EBCD) is an approach that enables staff and patients (or other service users) to co-design services and/or care pathways, together in partnership" (30). The variation in these definitions introduces ambiguity. For instance, the level of end-user relationship can be inferred differently between the terms 'involvement', 'collaboratively' and 'partnership', the latter describing more equal or joint engagement. The definition by Osbourne et al. is also the only one that details specific stages at which co-design could occur. The evolving nature of co-design is in part due to its newness as an idea. The potential promise of co-design has led to a rapid adoption of the approach by practitioners, which might explain why convergence towards a common definition and operationalization of co-design has not been reached.

Despite the lack of a uniform definition of the co-design process, recent studies seem to suggest that co-designed solutions have a positive impact on health outcomes. Case studies, systematic and narrative reviews of co-design in healthcare have shown improvements in the care experience, including improved patient knowledge, ability to cope with disease and better access to healthcare, reductions in falls and medical errors, improved patient satisfaction, better disease control, increased disease knowledge and reductions in cost (31–35). In the area of health technology, while positive findings have been reported, systematic reviews have not assessed the impact of co-designed technology as opposed to non-co-designed technology (15, 17–21). A specific evaluation of co-designed technology for elders ageing in place is therefore required. The objectives of this study are to: i) investigate the health and well-being outcomes of co-designed technology for elders (≥ 60 years); ii) to identify co-design approaches and contexts they are applied and; iii) to identify barriers to and facilitators of the co-design process with elders.

Methods

The study is reported and conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (36). The systematic review protocol was prospectively registered on the PROSPERO database of systematic reviews (registration number CRD42019133419). A copy of the PRISMA checklist is included in additional file 1.

Literature Search

MEDLINE, EMBASE, CINAHL, Science Citation Index (Web of Science), Scopus, OpenGrey and Business Source Premiere were searched in July 2018. A combination of MeSH terms and key words on the themes: older adults, community setting and co-design were used. An initial search strategy was developed in MEDLINE with an information specialist and converted for use in the other databases. Key journals (CoDesign: International Journal of Cocreation in Design and The Arts, Design Studies: The Interdisciplinary Journal of Design Research and the Interaction Design and Architecture journal) were also hand searched for further relevant articles. An updated search was conducted in September 2019. A copy of the search strategy conducted in MEDLINE is included in additional file 2.

Study Selection

Titles and abstract were initially screened for inclusion by a single reviewer. Short listed articles were full text screened by two independent reviewers for eligibility (Table 1). Disagreements were discussed and resolved with a third reviewer if required. When eligibility of a study was unclear from a publication an attempt was made to contact the author(s) for clarification.

Table 1 PICOS eligibility criteria

Criteria	Definition
Participants	Older adults ≥ 60 years of age living in the community or 'ageing in place'. Community dwelling was defined as adults living within their own home or within a senior living community who may be receiving some level of assisted care but are otherwise living independently. Participants residing in care homes, hospice or those receiving inpatient hospital care were ineligible.
Intervention	Health-related technology co-designed with the target population i.e. community based older adults, including information communication technologies (ICT), mobile and electronic health solutions or new treatments which involve technology as well as new ways of organising healthcare.
Control	For interventional studies the control group is defined as those not using a co-designed technology.
Outcomes	Any clinical or patient reported health and well-being outcome measures, experience of the co-design process and facilitators of and barriers to co-design.
Study types	All study types were considered: i.e. experimental, observational.
Other	Studies were restricted to English language only articles and the search was limited to the last 10 years. The date restriction was chosen to identify relevant technologies for the modern day context.

The concept of co-design

As there is no single definition of the co-design process we examined existing co-design definitions, identified common features and developed a set of eligibility criteria.

We operationalised the co-design process as: "The participation and equal collaboration between service providers, users, careers and the broader community to co-design health-related technology". It should include the following attributes:

1) Evidence of collaboration between consumer and provider beyond only information gathering from consumers

2) Evidence that consumer involvement is for the development of a product or service for the benefit of the consumer

3) Evidence that the consumer is involved in the development process at more than one point in time i.e. meaningful contribution

4) The 'consumer' may also be primary caregivers looking after elders, not including health professionals

Studies that only collected needs or ideas but did not actively engage elders further in product design were excluded (Point 1). For example, studies that interviewed participants on their needs but included no other elder involvement were ineligible. Products which were developed with elders but did not directly benefit them were also ineligible (Point 2). The co-design process is iterative and involves multiple stages of end-user involvement. Given the inherent flexibility in this description we set a minimum end-user involvement of at least two phases (Point 3). Specifically, end-users must have been involved in 'needs assessment and/or ideation of the product or service' (the first phase), and 'prototype development and/or pilot testing' (the second phase). Needs assessment refers to the collection of data identifying the problem and requirements from the end user. Ideation is defined as solution generation with stakeholders. Prototyping is the use, development and/or assessment of a mock-up of the proposed solution. Pilot testing is the evaluation of the final proposed solution in a real world setting. Application of the eligibility criteria allowed us to distinguish between studies with comprehensive and sustained elder involvement compared to those with more tokenistic engagement. For Point 4, studies where the end-user was the primary caregiver were only eligible if the caregiver was looking after an elder >60 years.

Data extraction and management

Data extraction was undertaken by one researcher and checked for consistency by a second independent researcher. Extracted data items included: study and population characteristics, intervention details, information on the co-design process, facilitators of and barriers to the co-design process, and outcome measures. The extraction sheet was piloted on a sample of papers and refinements made prior to full data extraction.

Quality Assessment

The Cochrane risk of bias tool was used to assessed the quality of studies reporting health and well-being outcomes (37). Two researchers independently assessed risk of bias and any disagreements were discussed. As no observational studies could be extracted no other quality assessment tools were used.

Data synthesis

We had planned to perform a mixed effect meta-analysis but due to insufficient outcome data this was not performed. Studies that included health and well-being outcomes were synthesised narratively. Facilitators of and barriers to the co-design process were extracted and organised according to the co-design framework outlined by Pirinen (2016). The framework contains five domains: collaboration, origination, processes, implementation and methods (38).

Results

We identified 11,681 unique articles of which 28 studies met the eligibility criteria and were included. The updated literature search identified a further 2,968 articles of which a further six were included (Figure 1).

Study characteristics

Characteristics of included studies are presented in Table 2. Studies were largely from Europe (n=28) and the remainder from Australia (n=4), America (n=1) and Canada (n=1). Twenty studies targeted older adult's general needs or concerns (≥ 60 years old) and an additional 14 targeted specific medical conditions or problems such as cognitive or physical impairments. Technological solutions included robots, online applications and software, smart televisions, computer games for exercise, global positioning solutions, smart home systems and design of care pathways. Solutions mostly targeted elders as individuals rather than group applications (n=30) and functions included: Support of Activities of Daily Living (ADLs), facilitation of social interaction, remote exercise or rehabilitation, education and disease self-management, safety monitoring, item location and reminder systems. Some solutions addressed multiple functions, for example, robots that were designed to support ADLs were also designed to be a source of social interaction.

Table 2 Study characteristics

Author, Country	Aim of project	Target population	Product designed
Blusi, 2018 (39), Sweden	To develop and design a model for enabling online participation in individualised meaningful social activities	Elders/Group-based	Computer based communication platform for remote social interaction
Botella, 2013 (40), Spain	To design, implement, and evaluate a mobile application to assist elders and carers to self-manage their medication	Elders/Individual-based	A mobile application (Virtual Pillbox) to help patients reduce medication errors and improve compliance
Brox, 2015 (41), Norway	To develop a exergame using 3D Kinect™ for home exercising	Elders/Individual-based	An online exergame, comprising of seven games, which tracks user movements to improve balance, leg strength and flexibility
Cahill, 2017 (42), 2018 (43), UK	To develop online, sensor-based infrastructures to support wellness, independence and social participation in elders	Elders/Individual-based	Ambient assisted living technology incorporating Internet of Things (IoT) and a sensor-based infrastructure to support wellness, independence and social participation
Cavallo, 2013 (44), 2014 (45), 2015 (46), Italy	Design, develop and test the ASTROMOBILE system for favourable independent living, improved quality of life and efficiency of care and to demonstrate general feasibility	Elders/Individual-based	The ASTROMOBILE system to support independent living. Composed of the ASTRO robot and an ambient intelligent infrastructure to localise users inside the domestic environment
Chevalier, 2018 (47), France	To create motivational and enjoyable solutions to help seniors practice appropriate physical activity at home	Elders/Individual-based	An online user interface 'Motiv@Dom' which supports physical activity in the home
Cozza, 2016 (48), Denmark	Developing innovative services for the welfare of citizens, with a focus on older people	Elders/Individual-based	Fall detection technologies: smartphone worn in belt/pouch or smartwatch connected to smartphone
Davies, 2016 (49), UK	To develop a toolkit of heuristics to aid practitioners making end-of-life care decisions for people with Dementia	Dementia/Individual-based	Four heuristics developed for use by practitioners in different settings to aid decisions in: i) eating/swallowing difficulties, ii) agitation/restlessness, iii) ending life-sustaining treatment, iv) routine care at the end of life

Fitrianie, 2013 (50), Netherlands	To develop a smart television platform - 'Care@Home', which integrates assistive living services for elderly in their homes	Elders/Individual-based	A low-cost smart television platform ('Care@Home') integrating assistive living services for elderly in their homes. The service provides a hub that connects elders to care networks, family, friends, communities as well as services for household help, healthcare, exercise programmes and entertainment
Frennert, 2013 (51), multi-site (Europe)	To develop a social and assistive robotic system that enables older people to live in their homes for as long as possible	Physically impaired (vision, hearing, mobility)/Individual-based	An autonomous social assistive robot able to self-localise, navigate safely, interact with humans through voice, text to speech, gesture recognition and a touch screen. Also able to detect and handle objects
Gallagher, 2009 (52), US	To develop, implement and evaluate the impact of an advanced practice nurse-run case-management programme in a senior citizen community centre	Elders/Individual-based	An advanced nurse run case-management programme "The Nurse Is In"
Giorgi, 2013 (53), Italy	To foster the active participation of older people as producers of resources related to their experience and know-how and to the activities carried out in the centres, to be shared in a community context	Elders/Group-based	An interactive table, i.e. a horizontal multi-touch screen based in a recreational centre, designed as a platform for resource sharing within the community
Goeman, 2016 (54), Australia	To establish and refine a culturally sensitive model of dementia support and care pathway to overcome barriers to health and social care services	Dementia/Individual-based	A culturally and linguistically diverse (CALD) specialist dementia nurse care model with quick reference cards to navigate services
Gronvall, 2011 (55), 2013 (56); Aarhus, 2010 (57), Denmark	To design technology to support vestibular rehabilitation at home	Vestibular dysfunction (dizziness)/Individual-based	Portable technology-based solutions to support home-exercises including a foldable RGB-LED light system, an interactive flower and a dart game
Hepburn, 2018 (58), UK	To co-create digital applications for elderly people	Elders/Individual-based	A tablet based digital app to help users with shopping
Hwang, 2012 (59), 2012 (60), 2015 (61), Canada	To develop the COACH system; a smart home interface which supports people with dementia in ADLs	Dementia/Individual-based	An intelligent home system (COACH) that leverages machine learning and computer vision to guide and support older adults with dementia through ADLs

Iacono, 2014 (62), multi-site (Europe)	To facilitate independent living of seniors at home using an assistive robot in a smart home environment	Elders/Individual-based	An autonomous social assistive robot (Care-o-Bot) able to self-localise; navigate safely; interact with humans (via voice, text to speech, gesture recognition and a touch screen) and ability to detect and handle objects
Kort, 2019 (63), Netherlands	To create a website providing ageing-in-place information for people living with dementia	Dementia/Individual-based	An online website offering information about home modifications for older adults with dementia and their family caregivers
Lehto, 2013 (64), Finland	The Safe Home project aims to investigate, develop, produce and evaluate interactive programmes and eServices - 'Caring TV', to support the health and well-being of elders in their own homes	Elders/Individual-based	An interactive platform 'CaringTV' hosting e-services which support health, well-being and social interaction
Leong, 2016 (65), Australia	To produce a companion robot in the form of a networked robotic dog	Elders/Individual-based	A robot dog (Hardy Hound) designed as a social companion with some assistive functions for the home
Lopes, 2016 (66), France	To conceive and assess an innovative item locator device that effectively addresses needs, capacities, and goals in older adults with cognitive disorder	Cognitive impairment/Individual-based	An item locator for the cognitively impaired consisting of a wand, RFID tags and headphones for sound directed location
Mincolelli, 2019 (67), Italy	To enrich the home with a collection of re-engineered objects equipped with sensors and actuators for the assistance of elderly users	Elders/Individual-based	An integrated system comprising of an interface, an armchair, a wearable device and a localisation system. Designed to support ADLs, reduce risk of fall or getting lost and increasing independence
Ogrin, 2018 (68), Australia	To design and evaluate the feasibility and acceptability of a foot health education app to prevent serious foot complications in diabetics	Diabetes/Individual-based	A diabetes foot health education app (Healthy feet). The app supplements health care provider intervention, encourages self-care and earlier help-seeking to prevent serious foot complications
Pettersson, 2019 (69), Sweden	To develop and evaluate an electronic fall prevention programme	Elders/Individual-based	A self-management digital exercise programme (SafeStepv1) that improves balance and strength

Pino, 2012 (70), France	To develop a socially assistive robot for elderly people with cognitive impairment	Mild cognitive impairment/Individual-based	A semi-autonomous, remotely controlled robot with speech control and a touchscreen. Provides cognitive and social support to the user through a suite of applications (task reminder, cognitive training, navigation support, and communication)
Pratesi, 2013 (71), UK	To develop an “intelligent” activity monitoring system that will support older and/or disabled people’s independence, safety and quality of life	Elders/Individual-based	An "intelligent" activity monitoring system (Smart Distress Monitor) that charts activity/inactivity patterns in the home living environment. The system learns patterns of behaviour, including deviations, using thermal imaging
Robinson, 2009 (72), UK	To create acceptable and effective technologies to facilitate independence for people with dementia	Dementia/Individual-based	An armband held device and an electronic notepad with location tracking and the ability for two-way communication
Sabater-Hernández, 2018 (73), Australia	To develop and implement a novel community pharmacy service (CPS) for screening and enhancement of self-management for atrial fibrillation	Hypertension, atrial fibrillation/Individual-based	A community pharmacist-led service incorporating patient education, self-monitoring and pharmacist consultation
Uzor, 2011 (74), 2012 (75), UK	To design and develop multimodal rehabilitation exercise games	Those at risk of falls/Individual-based	A home-based multimodal rehabilitative computer game incorporating body sensors for movement tracking
Van Velsen, 2015 (76), multi-site (Europe)	To develop a health service for detecting and preventing frailty among older adults by offering eHealth services	Elders/Individual-based	A technology-supported service for screening for frailty/pre-frailty in the elderly and a platform of e-health interventions including those designed to improve physical and cognitive functioning and knowledge of nutrition
Vermeulen, 2013 (77), Netherlands	The development monitoring system with a mobile interface that provides feedback to the elderly regarding changes in physical functioning and to test the system in a pilot study	Elders/Individual-based	A monitoring system including a bathroom scale for weight and balance, a grip-ball for grip strength, and a mobile phone with a built-in accelerometer for monitoring physical activity and functioning
Williamson, 2013 (78), UK	To create a digital reminder system for the home	Elders/Individual-based	A digital reminder system linking a paper-based calendar with a smartpen device

Wikberg-Nilsson, 2018 (79), Sweden	To further knowledge of user experiences of interface design and to develop a digital service to promote healthy and active ageing	Elders with sensory decline/Individual-based	A digital platform called HealthCloud that enables healthy and active ageing
Magnusson, 2012 (80), multi-site (Europe)	To develop 'ACTION' (Assisting Carers using Telematics Interventions to meet Older people's Needs), to increase the autonomy, independence and quality of life of frail older people and their carers	Frail elders/Individual-based	An information and communication technology based support service (ACTION) including online information, educational material and a call centre to support informed decision making

Health and well-being outcomes

Five Randomised Controlled Trials (RCTs) evaluated health or well-being outcomes (81-85). Outcome measures fell into four categories: Balance and falls, level of physical activity (including compliance) and physical function, Quality of Life (QOL) and mental health and clinical measures. Reported outcome measures across studies were too diverse to synthesise. Results were usually not statistically significant (Table 3). Statistically significant effects in favour of the interventions were reported for measurements of balance, physical function, SF-36 (pcs), SF-12, medication adherence, errors and missed doses. Statistically significant effects in favour of the control were reported for measurements of adherence to exercise, SF-36 (mcs) and cholesterol. Three additional studies included health and well-being outcomes but could not be extracted. One, a cross sectional study, had no comparison group (64), the second a pre-post-cohort, reported predictors of falls and disability (86) and the third, another pre- post-study (58), has yet to publish its health and well-being findings.

Table 3 Health and well-being outcomes

Measurement category	Measurement	Outcome
Balance and falls		
Brox n=54 (81)	Accelerometer	-
Uzor n=22 (87)	Timed up & go test, Falls efficacy scale	-
Uzor n=155 (83)	Berg balance scale	+ve
Uzor n=155 (83)	Falls efficacy scale, Balance confidence (CONFBAL)	-
Physical activity and function		
Brox n=54 (81)	Adherence to exercise time (mins/day)	-ve
Van velsen n=37 (84)	Adherence to exercise (times/week and minutes/session)	-
Uzor n=22 (87)	Adherence to exercise (sessions/week), Walking speed (cm/s), Stride length (cm), Stride time (secs)	-
Uzor n=155 (83)	30s Sit to stand test, 4-minute walk test	+ve
QOL and mental health		
Uzor n=155 (83)	SF-36 (mcs)	-ve
Uzor n=155 (83)	SF-36 (pcs)	+ve
Van velsen n=37 (84)	EQ-5D, SF-12 (pcs)	-
Van velsen n=37 (84)	SF-12 (mcs)	+ve
Botella n=99 (85)	Self-perceived health status	-
Other clinical measures		
Botella n=99 (85)	Medication adherence (MMAS-4), Medication errors, Missed doses	+ve
Botella n=99 (85)	Glycated haemoglobin (mmol/mol), Blood pressure (mmHg)	-
Botella n=99 (85)	Cholesterol (mg/dL)	-ve

Outcome rating: *statistical significance favouring control: -ve, statistical significance* *favouring intervention: +ve, non-significant changes -*

Risk of bias summary

Results of the Cochrane risk of bias assessment are presented in Figure 2. High performance and detection bias were identified in two trials (81) (84), high reporting bias in one trial (81) and high allocation concealment bias in one trial (84).

Co-design approaches

Co-design is an iterative process involving repeated cycles of product development and evaluation with stakeholders. Across studies and between design phases within individual studies, the intensity and method of elder involvement varied greatly.

Needs and Ideation

Studies varied in the number of design steps, number of rounds within each design step and the types of methods used. Workshops, focus groups, interviews and direct observations (in elder's home environment and during workshops) were commonly used for needs assessment and generation of ideas. Less frequently reported techniques included participant diaries (48, 66), sketching (59, 74) and use of photographs/videos (53, 69). There were multiple examples of participant priming in the design process i.e. preparing someone for involvement in the co-design process or in product use. For example, studies may include a practical assessment of existing products or introductory material on the research project and technological possibilities (66). Priming also occurred immediately before product evaluation in some cases. In one study a non-functional polystyrene robot was placed in the homes of elders prior to deployment of the functional robot. In this way participants became accustomed to having a robot in their home before evaluation of the functional robot took place (51).

Prototyping

Prototype use was common to almost all studies, although the purpose differed. Prototypes facilitated discussion, built knowledge and raised awareness of technological possibilities. Prototypes were also used to test the usability of a technological solution. Prototypes could be fully functional, partially functional or non-functional. An example of a non-functional prototype was a simple pen and paper drawing used to represent a tablet interface (53) or a full-scale robot shaped in polystyrene (51). Prototypes of a single aspect of a larger product were also created, particularly in robot designs. For example, a prototype of the robot user interface may be created separately from the full mechanical robot (62, 70).

Pilot testing

Twenty-three studies evaluated products in a real-world setting, of which five studies evaluated health and well-being outcomes of the final product (all RCTs). Evaluation in the real-world setting often occurred as part of prototype development, to test and refine functionality of the product before a final evaluation. Five studies discussed the use of a 'living lab' environment (44, 51, 62, 64, 66). Studies that used the term 'living lab', often used it incorrectly to refer to an experiment in a controlled laboratory setting and not in the field. For example, a mock-up of a living room may be set up within a laboratory to test the suitability of a prototype within that environment but not within an actual home. The conventional definition of 'living lab' is much broader "a user-centred, open innovation ecosystems based on systematic user co-creation approach, integrating research and innovation processes in real life communities and settings" (88).

Barriers to and Facilitators of the co-design process

Barriers and facilitators fell into four of the five domains outlined by Pirinen (38). No findings on barriers to the implementation of the co-designed solution were identified (Figure 3). The most frequently reported barriers and facilitators related to 'relationships and trust building', 'stakeholder knowledge building' and 'methods and skill in co-design'.

Relationship and trust building

Factors that enabled relationship building included: an early focus on relationship and trust building between stakeholders (51, 71); stakeholders finding common ground (51); making time for socialising among participants during design; using a suitable environment for socialising (51, 80); and keeping the co-design group small (80). Conversely, relationship building was hindered by existing hierarchies between stakeholders. For example, the traditional paternalistic relationship between healthcare professionals and patients hindered the design process, where there is a perception that professionals 'know best'. In cases where a hierarchy between stakeholders is a concern, researchers acted as advocates of the elder participants. This was reported in studies where professionals were reluctant to collaborate. In these instances, professionals did not value elder involvement or they viewed elders as 'weak' stakeholders (55, 71). Advocating for elders during co-design can therefore be important to overcome hierarchies and negative perspectives, but it needs to be performed carefully. Some authors noted that over-reliance on researchers could lead to elders becoming dependent on the researcher to advocate their views, leading to misrepresentation. Elders could also attempt 'to please' researchers in their responses to design-related questions (41, 55).

Stakeholder knowledge building

An important aspect of co-design is knowledge building among stakeholders. Knowledge building aims to improve understanding of different stakeholders' perspectives and experiences, knowledge of a disease or condition to be addressed, and what could be achievable through technological solutions (48, 51, 55, 70, 71). A lack of knowledge could cause unrealistic expectations and hinder the design process (55, 71). For example, participants may become demotivated if they incorrectly blame themselves for product faults (41). Knowledge building to overcome the 'digital divide' between elder participants and designers would help realise the full design potential of the co-design process (53, 55).

Methods and skill in co-design

Skill and knowledge in co-design techniques are needed to avoid design ineffectiveness. Skill in co-design techniques is applicable to researchers, professionals and the end-users themselves. In one study, participants did not know where to begin with a particular design activity as they had 'never done it before' (74). In another study, technology experts were reluctant to engage with elders as the participatory approach was 'alien' to them (71). A lack of understanding of the co-design process also led to stakeholders not understanding why it is time consuming (55), which can hinder support from the participants.

When working with elders, collecting observational data (41, 48), limiting the number of interview questions (41, 74) and using multiple design techniques (51, 62) were reported as useful tactics in the co-design process. These tactics maximised the ability of participants to participate in the co-design process. Using mock-ups or scenarios was also found to facilitate the process of co-design (48, 51, 53, 55, 59, 62, 74), but timing of mock-up use was important. Too early and the design process may be compromised, as participants may dismiss concepts based on the aesthetics of the mock-up alone (48, 55).

Discussion

Preserving elder's independence has become an increasingly important goal for healthcare systems. Health technology can support safe and active ageing in the home and in the community, but its acceptance and use can be sub-optimal without consideration of the end-users' needs and preferences (22). Participatory approaches, which involve end-users in the solution development process, are now commonplace in healthcare (25-27). Co-design is one such approach and involves stakeholders collaborating in an iterative manner. Our review found that the impact of co-designed technology for ageing in place remains unclear. However, researchers frequently commented on the value of elder involvement in terms of solution generation and concept refinement.

The studies we included studies were exclusively from developed western countries, in particular Europe. This may be partially explained by the inclusion of only English language articles. Technological solutions that were co-designed were diverse and often multi-functional. For example, robots that encouraged social interaction were also designed to assist in ADLs. Elders with Dementia were commonly targeted end-users, probably due to their higher need for assistance at home. Chronic diseases were less frequently addressed. For example, no technological solutions were designed for elders with arthritis or depression. Only two studies targeted heart diseases (73) and diabetes (68). This may be explained by our eligibility criteria ($\geq$ 60 years). Chronic diseases often occur at an earlier age, thus studies that involved younger groups were not included in our review. Future studies should focus on co-designing solutions for chronic diseases with an elder-specific focus.

How elders are engaged in the co-design process varied greatly. We found a mixture of approaches including workshops, interviews, focus group discussions, sketching (59, 74), video tours (53), participant diaries (48, 66) as well as the use of low and high functioning prototypes during the co-design process. Using a variety of methods fits with guideline recommendations. A mixture of methods improves opportunities for participant contribution, because participants may have different ability levels and physical capabilities (29, 89). For example, an elder who is hard of hearing may struggle to contribute in a focus group setting, but he or she could interact more effectively in a one-to-one interview. The range of ways elders were engaged in the design process could also be a reflection of the broad definition of the concept of co-design and the heterogeneity of technologies developed. The development of an app may dictate a specific approach of collecting data from participants that may be less useful in the design of a smart home. The diversity of methods used in co-design processes makes it harder to compare across studies and identify what approaches are effective and what are less appropriate.

The intensity of elder involvement in the co-design process varied as well. Not all studies included all four phases (needs, ideation, prototype and pilot testing in the field) and the number of rounds within a phase were different between studies. In some cases, the absence of the later co-design phases was an indication of the stage of development, that is, papers reported studies that were ongoing and have not reached the latter stages of co-design process (i.e., field testing). In other studies, different groups of elders were involved in different phases of the co-design process, as the project progressed. This could lead to a lack of participant continuity and potentially cause a mismatch between needs and outcome. It must be acknowledged that the co-design process requires the commitment of significant amount of time and resources. Some projects may have to rationalise limited resources and determine when and how elders are involved in the design process. This can impact the number and type of sessions conducted (some co-designed phases might be skipped or minimised). It remains unknown as to what impact the variability in implementing of the co-design phases has on the design output. It is unclear what level of involvement is ideal and how resource limitations could hinder proper execution of the co-design process. Many studies were excluded due to a clear lack of elder involvement, despite claiming to be ‘co-design’ projects. Researchers should refer to existing co-design guidelines and toolkits (29, 89) to understand the degree and breadth of stakeholder involvement required in the co-design process.

Elder needs and physical capabilities can impact their involvement in co-design. Age related physiological changes and the presence of disease require researchers to be thoughtful in adapting co-design methods. For instance, one study reported that during focus group discussion, researchers purposefully moved close to each elder when asking questions to make sure they could hear researchers’ questions clearly (41). Lack of consideration of age-related issues can lead to elders reluctant to participate. Authors suggested increasing allocated time, providing a supportive environment, using short questionnaires, taking time to direct questions to each participant in group discussions and ensuring questions are understood (41, 80) to avoid design difficulties with elders. Overall if researchers can adhere to inclusive design principles, such as the Universal Design principles that consider equity, flexibility, simplicity, perceptibility, tolerance for error, low effort and accessibility (90), many of the challenges of designing with elders can be managed.

Only five studies evaluated health and well-being related outcomes (81-85). Studies tended to limit to measuring product usability and end-user satisfaction. In the five studies that examined health and well-being outcomes, there were insufficient data to draw definitive conclusions. A recent systematic review of co-creation and co-production in healthcare, reported a lack of outcomes measurement as well (91). Even though usability and utility of technology is important, if it doesn't positively affect the health and well-being of the consumer, it is difficult to ascertain the value of the new technology in the long run. It would benefit healthcare professionals and end-users to commit a bigger part of the resource for technology development to systematic evaluation of new co-designed technologies. Researchers should consider evaluating health-related impact including disease control measures, quality of life, physical functional status, access to service and service experience, as with other areas of healthcare (31, 33, 34, 92). Without proper evaluation, it will be difficult to support greater adoption of the co-design process because it is resource intensive and requires multiple stakeholders.

Limitations

There is no single definition of co-design in the literature, which has led to a high degree of terminology variability. It is possible our literature searches did not include all relevant co-design terminology and studies were missed. We attempted to minimise this risk by expanding our list of search terms. In many cases, the methodology reported in the papers was limited and made it difficult to ascertain whether a study was truly co-design. Where possible we searched for linked articles and contacted authors for clarification. In addition, one of our eligibility criteria required that elders must be involved in at least two phases of the co-design process. We acknowledge there is no consensus on this requirement and thus we may have excluded relevant articles that had lesser elder involvement in their design process. However, given the range of interpretations of what co-design is in the field, we deemed it important to include this criterion to increase our confidence that included studies involved elders in a meaningful way.

Conclusion

Co-design is an evolving methodology that is increasingly adopted by healthcare organisations to improve care and well-being of end-users. Our review found a diverse set of technologies developed to support elders to age in place. However, evaluation of health and well-being outcomes was limited and definitive conclusions could not be drawn. Future efforts should continue to involve elders and more effort should be committed to evaluating the impact of co-designed technologies.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests

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Authors contributions

JS and LYW conceptualised and managed the project. JS conducted the search. JS, LYW, CLS and AB screened articles for eligibility. JS, CLS and AB extracted data. JS and LYW analysed the data. JS and YW drafted the manuscript. All authors read and approved the final manuscript.

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Figures

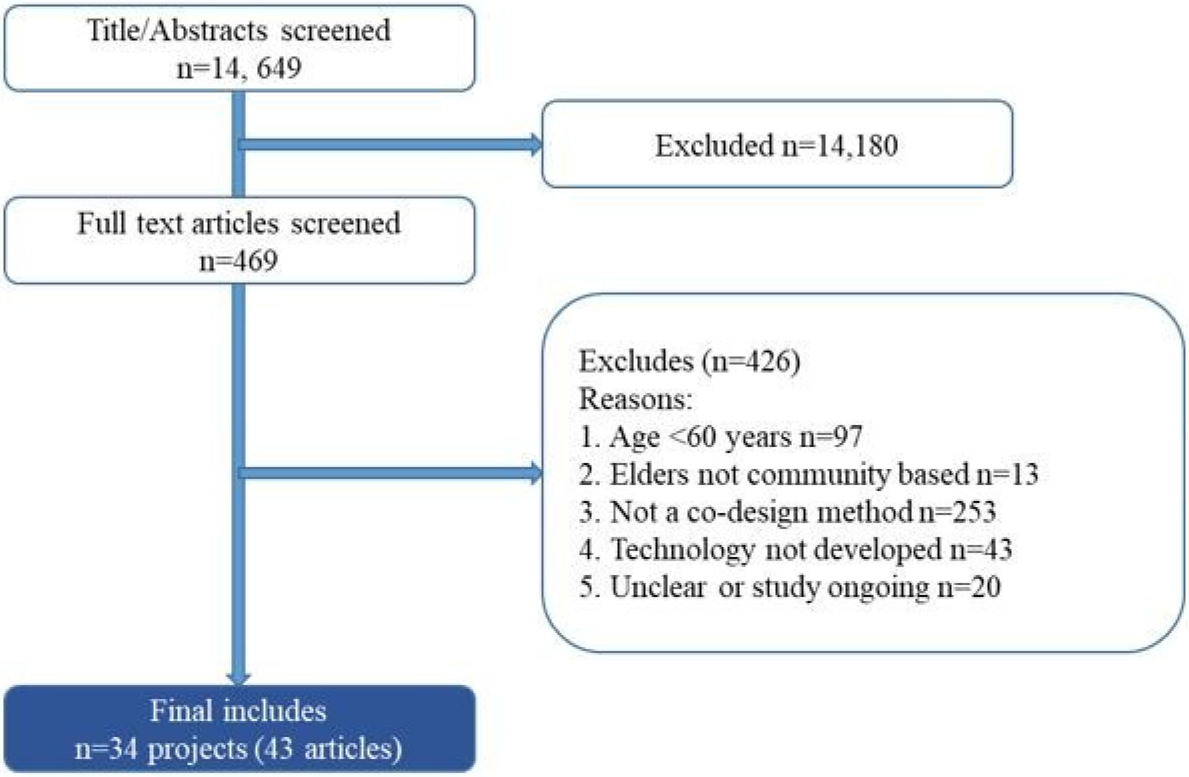

Figure 1

PRISMA flow diagram

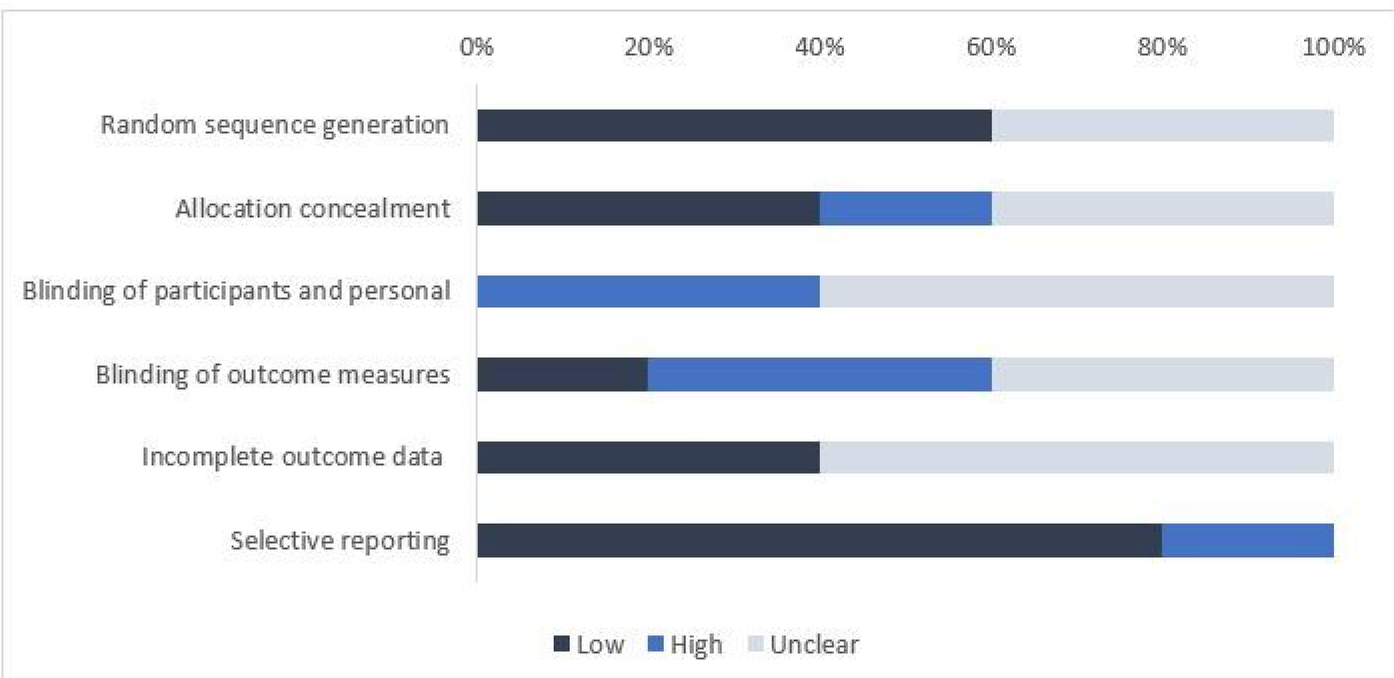

Figure 2

Cochrane risk of bias assessment

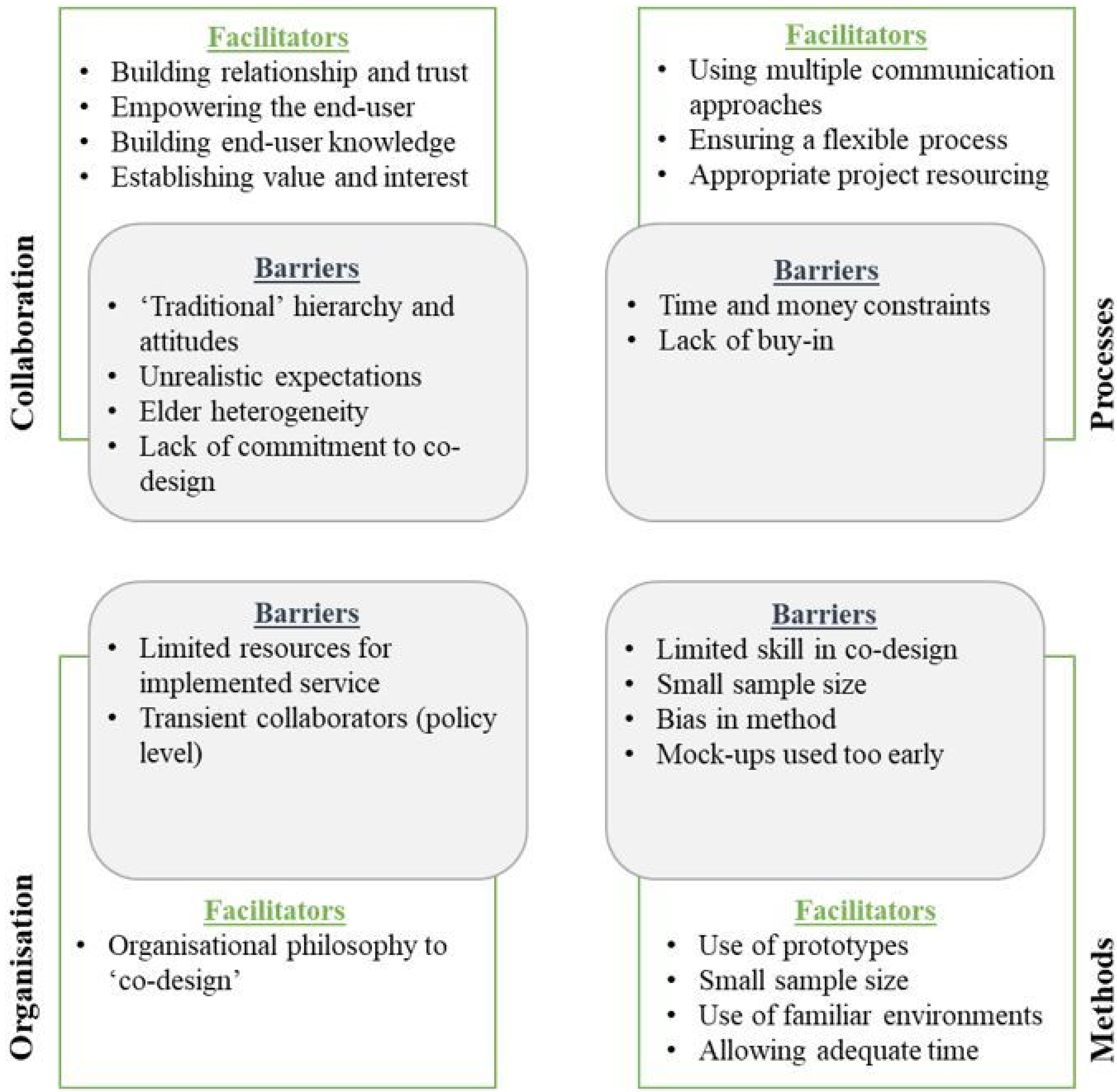

Figure 3

Examples of barriers and facilitators to co-design

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