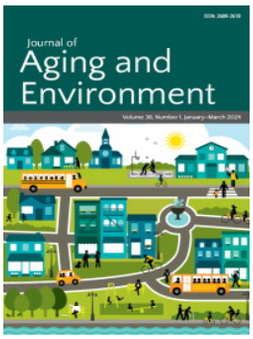

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Housing Design Evaluation Research for People Living with Cognitive Change: A Systematic Literature Review

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ABSTRACT

Research suggests that improvements to home design may enable us to live better with cognitive change as we age. However, few innovations have been fully evaluated. The paper systematically reviews 47 items of evaluative literature. Research design and quality are varied. Qualitative analysis of literature demonstrates the need for a holistic approach that includes older people's diverse perspectives, examples of promising practice that responds to individual needs, and gaps in research on scalability and economic viability of innovations. The context of design improvements is found to be critical.

KEYWORDS

Ageing; cognitive aging; dementia; housing design; later life; review

Introduction

The significance for older people experiencing cognitive change of a familiar, supportive living environment has long been documented and is rarely questioned (Hillcoat-Nalletamby & Ogg, 2014). However, cognitive changes that come with age, which include processing speed, memory, reasoning and executive functions (Deary et al., 2009), may make our homes more difficult to live in, magnify problems that come from deprivation and poor physical health, and result in moves to unfamiliar environments, including hospitals or communal establishments such as care homes. Cognitive changes, including dementia (that, according to Wittenberg et al. (2019), 7% of us will develop), are the most significant factors stimulating a move to residential care (Deary et al., 2009). Challenges include for example incontinence and behavioral issues, which are especially difficult for family carers (Gaugler et al., 2009; Műller-Hergl, 2004).

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There is some evidence that modifications to the living environment may make a difference to life with cognitive change. For example, using color contrast in bathrooms can help people identify sanitary ware correctly and help manage continence (Greasley-Adams et al. 2014); orientation aids can assist with behavioral distress (Fleming et al., 2016). However, the evidence base needs strengthening, and an extensive literature review (Bowes & Dawson, 2019) shows previous research has several problems. There is a preponderance of small-scale experimentation and trials (e.g., Beach, 2015; Evans & Vallelly, 2007) and limited engagement with multiple stakeholder perspectives including architects, developers, housing providers and people living with cognitive change. There is often a narrow focus on people with mild-moderate dementia living in care settings, rather than on people living at home. Research that has analyzed large datasets tends to focus on multiple factors influencing cognitive change, but not on housing issues (e.g., Gale et al., 2020).

There have been previous attempts to improve design for cognitive change, such as through provision of guidance (e.g., Fleming & Kelly, 2017), establishment of principles and values (Fleming et al., 2022), and initiatives such as 'dementia-friendly' environments (Hebert & Scales, 2019). Quirke et al.'s (2021) extensive searches of publications since 2000 identified 19 tools aimed at improving environments for people living with dementia, covering a wide range of settings. However, the potential for delivering design features that can support healthy cognitive aging in place and at scale has not been realized. Housing providers, whilst showing interest in innovations (e.g., Greater Manchester Combined Authority [GMCA] 2018), are often skeptical of their value and perceive high costs (Centre for Ageing Better [CAB] 2019). National housebuilders, who represent 80% of new UK housing provision (Statista, 2023), are reluctant to depart from existing designs, risking a reduction in return on their investment, and therefore have not built housing to support healthy cognitive aging.

To inform and to provide a baseline for further research which will improve the patchy evidence base, this literature review focuses on identifying publications that have *evaluated* the design of living environments for cognitive aging, emphasizing homes in the community. It considers literature that addresses the core problems indicated above through systematic evaluation, excluding literature that describes, documents, develops or promotes home design without evaluation. Our focus is therefore narrower than some earlier, more general, reviews, such as Marquardt et al. (2014), Chaudhury et al. (2018) on long term care settings, and Bowes and Dawson (2019) on multiple settings. Our intention in this review is that by focusing on *evaluated* design innovations, we emphasize the stronger evidence base for change. The key issues we explore are the outcomes that are

considered important and then assessed; promising practice and facilitators and barriers to successful implementation of change; scalability of innovations, particularly in reference to contextual factors such as inequalities; and cost effectiveness.

Methods

Our approach builds on that used in earlier reviews (such as Bowes & Dawson, 2019). The review included both academic and nonacademic literature, searched during July–August 2021. The databases searched were EBSCOHOST and Web of Science Core Collection, which between them cover a wide range of literature. The search terms are identified in Table 1.

Table 2 lists the inclusion and exclusion criteria. The publication date of 2000 was set in light of the rapid development of interest in and research on design for cognitive aging during the 21st Century, and to ensure that the studies included were more likely to be up to date and therefore relevant to current conditions and policy environments. Prior to 2000, as Day et al.'s (2000) review demonstrates, the overwhelming focus of research on designing environments for people living with dementia was on institutional settings, and the most usual outcomes considered were those relating to behavior of people with dementia, including agitation, aggression, violence and "exit attempts." Over the 2000s, a changed consensus has emerged regarding design that influences how researchers frame and measure the issues they examine. Fleming et al.'s (2022, p. 3) important work identifies the extent of this consensus, which focuses on "dignity, autonomy, independence, equality of opportunity and non-discrimination" and encapsulates an emphasis on the person living with cognitive change. Whilst any cutoff date for including literature is in some respects arbitrary, our review intends to include work that is more in keeping with these modern perspectives, reflecting increased focus on personhood with decreased focus on disease described by Brooker (2012) and that considers homes in the community.

Table 1. Search terms used in EBSCOHOST and Web of Science Core Collection.

SU (evaluat* OR testing OR measur*) AND
AB ((intervention* OR innovat* OR modif* OR adapt* OR renovat* OR remodel* OR refurb* OR enabl* OR support* OR assist* OR aid* OR support* OR access* OR technolog* OR smart OR device* OR electronic* OR monitor* OR telehealth OR telecare OR telemed* OR domotic*)) AND
AB ((hous* OR home* OR accomm* OR residen* OR dwelling* OR "assisted living" OR shelter* OR speciali* OR "extra care" OR apartment* OR cottage* OR environment* OR locat* OR neighborhood* OR neighborhood*)) AND
AB ((aging OR aging OR older OR elder* OR retire* OR senior* OR dementia* OR Alzheimer* OR Parkinson* OR disabled OR disabilit* OR impair*))
Where SU is 'subject' and AB is 'abstract, with further limits on date of publication (from 1 January 2000), language (English) and document type ('articles' in Web of Science, 'academic journals' in EBSCOhost).

Table 2. Inclusion and exclusion criteria.

	Inclusion Criteria	ExclusionCriteria
Studies	Language: Full text in English Publication Date: Studies first published on or after 1 January2000 Study Types: Reporting primary research (qual/quant/mixed), case studies, industry publications*(reviews of published articles reporting primary datawill be checked to test sensitivity of search strategy but not as data)* Setting: Studies conducted in any domestic, residential, or supported living setting.	Language: Full text is not in English Publication Date: Studies first published before 1 January2000 Study Types: Study protocols without primary research, articles which do notreport primary research, conference abstracts, conference proceedings and theses. Setting: Studies conductedoutsidea domestic, residential or supported living setting.
Population	Human populations, older adults with or without a diagnosis of dementia or cognitive impairment.	Non-humanpopulations (inc. animal studies, mathematical modeling etc), younger adults, children
Intervention	Interventions designed to assess the effects of home and garden design innovations	Medical or pharmaceutical interventions that do not include an environmental component.
Outcomes	All outcomes, e.g.: Changes in objective or subjective physical, social, and psychological health Changes in quality of life, or well-being Changes in function related outcomes Changes in Behavioral and Psychological Symptoms of Dementia Changes in cognition related outcomes Changes in economic outcomes Engagement with intergenerational orcommunity-basedaspects Changes in transition from community living to residential care	None

Only items that reported primary research including case studies and industry publications were included. There is a considerable literature in this area that describes ideas or promotes particular approaches to design. Much of this does not include primary research or evaluation, and this type of material did not meet our inclusion criteria. Our population of interest is broadly defined: whilst our primary interest is in aging with cognitive change, many people experiencing this do not have and do not require a medical diagnosis. It is also difficult to single out cognitive aspects from the multiple changes people experience as they age, and design for cognitive change inevitably needs to consider these other changes, including physical and sensory changes. We did not include literature that focused only on outcomes for caregivers.

The PRISMA diagram (Preferred Reporting Items for Systematic Reviews and Meta-Analyses—Figure 1) illustrates the results of the searches and the process of reviewing items identified to extract those that met the criteria for inclusion. Items were sifted by title, abstract and full text by members of the research team, with a checking process in place to review decisions and ensure consistency.

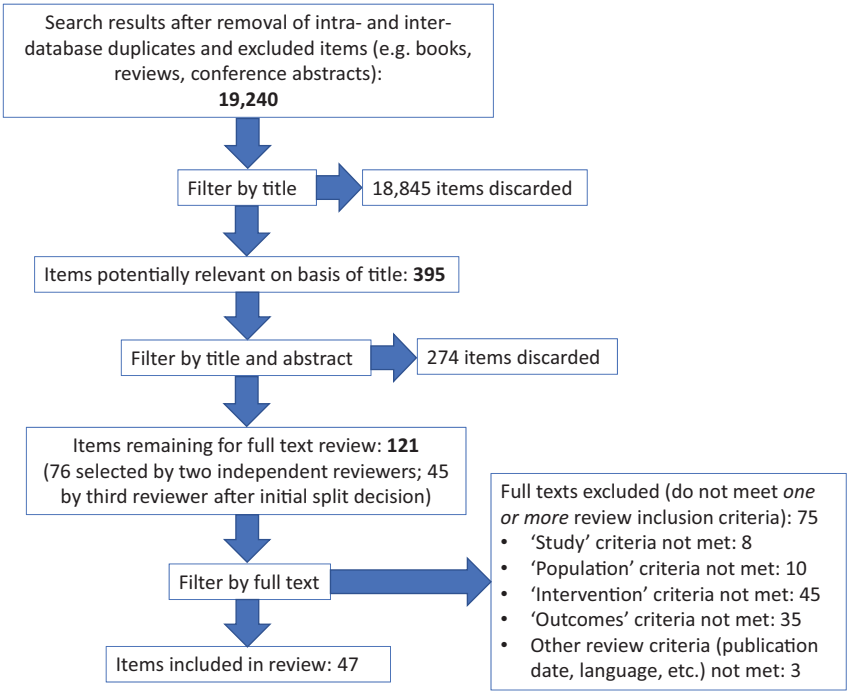

Figure 1. PRISMA diagram.

The full texts included were reviewed and quality assessed by members of the research team, using a pro-forma that allowed on-line review. The pro-forma directed reviewers to identify the study type, and having done so, to assess the item according to established criteria relating to the conduct of that study type. The sources for these widely recognized criteria are listed in the supplementary material. After responding to the questions based on the quality criteria, readers were asked to come to a judgment of the overall quality of each item assessed. These judgments were "lower quality," meaning the study had major limitations; "medium quality," signifying important limitations; and "higher quality," for studies with only minor limitations. Following initial assessment, the reviews were then checked by other team members to ensure accuracy and consistency of judgment across the team. Sixteen reviews were revised following this process.

The descriptive overview and discussion of the literature that follows derives from qualitative review of the findings. The nature of the literature means that quantitative meta-analysis is not possible.

Overview of literature

Whilst the literature on the design of environments for people living with dementia is extensive (Bowes & Dawson, 2019) and there are many initiatives

Table 3. Research designs and quality assessments.

Study research designs of included publications	Higher quality	Medium quality	Lower quality	Total
Randomised Controlled Trial (RCT)	4	6	1	11
Mixed methods	1	7	1	9
Qualitative study	2	5	1	8
Before and After Study without Control	0	6	1	7
Cross-sectional study	2	3	1	6
Cohort study	1	1	0	2
Repeated Measures Study without Control	0	1	1	2
Non-randomised Controlled Trial	0	1	0	1
Interrupted Time Series Study without Control	0	0	1	1
Total	10	30	7	47

across the world that have been presented as exemplary (Fleming et al., 2020), studies that *evaluate* designs are surprisingly few. There is an emphasis in much of the (excluded) literature on assessing need, promoting, and piloting various design ideas and planning for the future. Where evaluations are conducted, many of these are quite narrowly focused, considering design changes in isolation, or focusing on specific items of technology, rather than considering home design more generally.

Methods used in the studies were varied, as Table 3 indicates. Eleven RCTs and one non-randomized controlled trial included controls. The largest group of studies (eight qualitative and nine mixed methods) used qualitative data. Only one study (Clarke, 2014) used large scale, quantitative data. In terms of quality, most studies were assessed as being of medium quality, across the range of designs. Higher and lower quality studies also included different designs. The largest number of high-quality studies were four RCTs, a small proportion of the studies included. The supplementary material includes a table listing the quality assessments and the justification provided by reviewers.

Some of the literature exhibits significant methodological limitations. Most notably, several studies included small samples. Lapierre et al. (2019) for example worked with only six older women in their evaluation of camera-based monitoring. Niva and Skär's (2006) evaluation of home adaptations included only five people. Samples are also of limited diversity, with very few identifying participants of lower socio-economic groups or from diverse ethnicities. Many of the conclusions drawn are therefore cautious. Kim and Choudhury (2021) for example highlight the limitations of their study that included only residents of an older people's housing facility. Gitlin et al. (2006) acknowledge that their volunteer sample of community-dwelling older people might have been people with a stronger-than-usual motivation to learn new support strategies.

The mixed quality of the research presents a challenge in terms of drawing lessons from the literature. In the discussion that follows, in accordance with the recommendations of Nutley et al. (2013) on using evidence

pragmatically, we are drawing lessons that are supported by several research sources whose individual contribution is small, but whose collective contribution is more promising and allows firmer conclusions to be drawn. Linked to this, we do not subscribe to a hierarchy of evidence relating to research approaches. With Boaz et al. (2019) we recognize that there is not a simple or direct relationship between research findings and implementation of innovations and that in the real world, research evidence will interact with context, with those delivering policy and practice and with people asking for and on the receiving end of innovation, and that outcomes will reflect that interaction.

Thematic discussion

Outcomes measured

A wide range of outcomes was identified in the studies. Table 4 shows the range, noting that studies frequently referred to multiple outcomes. Generally, outcomes were defined by the researchers, with few examples of consultation with older people on their own preferred outcomes. Overall, the most usual outcomes considered were acceptability and usefulness of the interventions evaluated.

Some research sought to focus on one particular outcome and to assess the impact of the environment in relation to that. These studies have a

Table 4. Outcomes considered in the studies.

Outcome	Number of mentions
Acceptability of intervention	17
Usefulness of intervention	16
Falls/risk of falls	11
Activities of Daily Living	10
Physical functioning	9
Wellbeing/quality of life	7
Psychological distress	6
Social support	5
Fear of falls	5
Sleep	4
Self-reported health	3
Autonomy/independence	3
Cognitive changes	3
Safety	3
Costs analysis	3
Behavioral changes	2
Adherence	2
Life impact	1
Pain/discomfort	1
Adaptations made	1
Accessibility of home	1
Nutritional health	1
Hospitalisation	1
Time orientation	1
Adaptive strategies	1

strong emphasis on physical functioning, considering factors such as mobility, sleep, and falls.

Preventing and reducing falls and/or fear of falling are frequent concerns, mentioned 16 times, with environmental modifications being seen to address them. Results vary. Kamei et al.'s (2015) intervention entailed training for older people in home safety measures and aimed to reduce falls. Their RCT showed that the intervention raised people's awareness of hazards in the home and showed people what environmental changes they could make. The trial confirmed that falls could be reduced through this intervention. Crowell and Sokas (2020) were able to demonstrate a reduction in falling and fear of falling following a programme of hazard reduction in people's homes. A different result was produced by Mackey et al. (2019), whose study of flooring considered whether a softer landing type of flooring (under hospital grade vinyl) could reduce serious injuries from falls. This is one of few studies reporting less positive results, in that, there was no significant reduction in severity of injuries through using this method.

Sleep and circadian rhythms are considered by researchers including Thölking et al. (2020) in communities and Sloane et al. (2007) in care facilities who consider, respectively, nighttime lighting and bright light use during the day. Both were able to demonstrate positive effects, though did not achieve strong results. Both are cautious in their recommendations.

There are indications in the literature that a more holistic approach to considering outcomes is merited, as this can help identify pros and cons of environmental modifications. The RCT of bright light and melatonin (Riemersma-van der Lek et al., 2008) for example used standardized scales covering various symptoms of dementia, activities of daily living, behavior, and mood. The results showed positive effects on some outcomes (circadian rhythms) but negative effects on others (mood). This study suggests that focus on a limited set of outcomes may risk adverse (and positive) effects being missed. A further example is Lauriks et al.'s (2020) exploration of the impact of technological environmental changes on quality of life and falls for people with dementia, care needs, restraint use and employed carers' job satisfaction. The environmental modifications studied included lighting, re-arrangement of spaces to allow residents to move around the home and a system of alarms. Outcomes were measured using a combination of standard instruments and routinely recorded data. The rationale for using these outcomes is linked to gaps in existing literature. Lauriks et al. (2020) are able to demonstrate that effects are mixed in terms of the different outcomes: for example, they find positive effects for quality of life and falls, but no effects on care needs, restraint use or carers' job satisfaction.

In several cases, researchers adopt a more critical stance on outcomes, generating relevant lessons for future research. For example, de Jonge and Stevens (2016) consider the effectiveness of routine (service defined) outcome measures for understanding the impact of assistive technologies (AT), comparing these measures with qualitative data. They find that the routine measures do not identify the full impacts of AT, especially regarding improved autonomy and engagement in preferred activities. Similarly, Kristoffersson et al. (2019), who included reflective, qualitative interviews in their study, found that standard instruments were problematic because they seemed to relate to issues that, for their respondents, had little to do with the ambient technology being evaluated. Furthermore, they stress that the qualitative material was important for enabling them to understand some negative responses to the standard questions, that were usually due to the broader circumstances and life events being experienced by participants.

In this literature that takes a more critical perspective on outcomes, the importance of considering the views of older people themselves about their environment is emphasized, with several studies providing significant insights both into these views and their implications for designing environments. For example, Lapierre et al.'s (2019) work demonstrates dynamic views that influenced design changes. Their small study examined older women's responses to a system of video monitoring in their homes that was intended to identify incidents such as falls and to check welfare. They found that the six older women involved in the study were generally positive, noting that their views evolved as the technology was implemented and developed. This is important as it highlights that the novelty of a system may influence views at implementation, and views may change as users become accustomed to it.

Paying attention to older people's perspectives should expose the potential variety of views. For example, Costa et al.'s (2021) Italian study emphasized the importance of tailoring interventions to the individual and ensuring that people were involved in discussions about adaptations to their homes. However, the literature as previously noted shows challenges in terms of understanding diversity of perspectives and the need to understand individual circumstances to make sense of views.

The review highlighted some outcomes that are rarely considered, but that are identified in other literature (e.g., Garcia & Trascastro, 2021) as being of significance to older people themselves. Sociability, social contact, friendship and kinship were rarely considered. Exceptions include Brown et al.'s (2008) work in a Hispanic neighborhood in Miami, Florida, and Bowes and McColgan's (2013) study in West Lothian, Scotland, that includes consideration of social and familial relationships. van der Heide

et al. (2012) unusually explored the impact of an intervention on loneliness and social support: CareTV provided a range of services including 24/7 access to a nurse practitioner and did have a positive effect on reducing feelings of loneliness. From older people's own points of view, Asghar et al.'s (2018) study highlights a preference for using technology for socializing and emphasizes the need for technology to be tailored to individual requirements.

Promising practice

We reviewed material in the literature that identified promising practice in home design, and also some significant barriers to implementation.

The literature identified included studies that emphasized the benefits of early intervention, that is, putting design features in place before people had reached critical points of need. For example, Wilson et al.'s (2009) working in the USA with people aging with a disability argue that earlier intervention could increase the effectiveness of assistive technology in the home in slowing deterioration of capacity. Similarly, Petersson et al.'s (2009) longitudinal study of the impact of home modifications over a six-month period found that these had continuing benefits, and that, while people waited for modifications to be installed, their difficulties increased. From this, they draw the conclusion that earlier intervention will have greater benefits. This would need to be balanced against the reluctance of some people to identify as needing help themselves.

For design interventions to be successful the people receiving them need good information, that needs to be reinforced. Stark et al.'s (2018) feasibility trial of individually assessed interventions in people's homes included a period of therapist support, to ensure that the participants understood and could use the adaptations to obtain maximum benefit. Gitlin et al.'s (2006) intervention included six interactions with professionals over six months, working through measures tailored to the individual. Overall, their RCT identified lasting positive outcomes twelve months after the intervention was complete, though they are careful to emphasize the difficulty of identifying the precise impact of professional involvement. Guitard et al.'s (2013) evaluation of artificial intelligence-generated prompts to people aged 80+ to use grab bars when bathing demonstrated that recognition and use of some home modifications may require reinforcement for example through these prompts.

Change preceded and driven by consultation with older people appears to promote good levels of effectiveness of design interventions. For example, Asghar et al. (2018) argue for the importance of user perspectives, suggesting that failures in effectiveness of assistive technology

are likely to occur if user views are not considered. Hunter et al. (2021) make similar claims for a co-designed smart home telehealth system.

Several studies emphasize the importance of recognizing the individual's context and circumstances and delivering design interventions that are flexible and can be tailored to individual needs. For example, Costa et al. (2021) examined involvement of people living with disabilities in making decisions about home adaptations, arguing that if people are involved and if adaptations can be responsive to individual needs, there is a greater chance that they will be successful and promote independence and autonomy as these were intended to do. Outila and Kiuru's (2021) study identified specific circumstances in which users will or will not make use of video conferencing technology provided in their homes: they found that devices need to be congruent with the needs and wishes of the individual. Stark et al.'s (2018) important study focused on individually tailored home modifications, such as handrails and devices for aiding bathroom use. Their process evaluation involving 115 participants, described as "community-dwelling frail older adults," demonstrated effectiveness over one year and acceptability, with positive outcomes for daily living and falls prevention.

These examples of promising practice suggest that barriers to implementation may include bad timing, poor information, failure to consult older people and taking an inflexible "one size fits all" approach. Other specific barriers are also identified in the literature. One is that where design features are in place, they may not be in optimal use. A Dutch study (de Craen et al., 2006) explored assistive device use and needs in a group of 147 people aged 85+ living at home. Of 591 devices, 74 were not being used, and 66 of the respondents were found to have additional needs. The researchers highlight the potential role of additional occupational therapist support in ensuring use of adaptations and support to cater for unmet needs. Secondly, context may prove a barrier to successful implementation. For example, Bowes and McColgan's (2013) evaluation of a local authority wide telecare implementation highlights contextual factors including ageism in society, which stigmatizes the receipt of care, and the organization of care work, which can prevent optimal deployment of home design features from the service users' points of view. Thirdly, interventions can have unintended consequences. An RCT of bright light therapy and melatonin (Riemersma-van der Lek et al., 2008) highlights that intended positive impacts may be compromised by unintended effects. They found that whilst the interventions had a positive effect on sleep, restlessness and aggression, melatonin had less positive effects for mood.

Scalability

None of the literature identified and included in the review included explicit discussion of or data about scalability. However, some initiatives had been implemented at larger scale, notably by municipalities, and these studies provide some material that can inform discussion of this critical issue.

One important study (Danziger & Chaudhury, 2009) evaluated a city-wide programme of "adaptable housing" (i.e. housing that could be adapted for people with varying support needs) in Vancouver, Canada, that aimed to support aging in place. The programme involved corporation-built social rented housing that incorporated design features that "future-proofed" accommodation as residents developed support needs. These features included for example accessible entranceways, wider doorways, non-slip flooring, switches installed at appropriate heights, strong lighting, and reinforced walls in bathrooms to allow for future installation of grab rails. The evaluators spoke with older people who had been living in several of the complexes about the design features of their homes. Findings showed generally high levels of satisfaction with the homes, and appreciation of the design features both for people who had developed support needs and for those who were thinking about their future needs. At the time of the evaluation, there were 400 such housing units in the city, with a further 1,000 being developed. This study is able to demonstrate appreciation for age-friendly design features incorporated in housing and that this can be delivered at scale by a local authority. Importantly, the programme had flexibility built into the housing designs, and many of the participants in the study spoke about their individual needs and future needs, and particular alterations they would make to their homes in the future. Comparable examples include the local authority-wide telecare implementation in West Lothian, Scotland (Bowes & McColgan, 2013) and Brown et al.'s (2008) evaluation of housing in a Hispanic neighborhood in Miami, Florida.

Falls prevention programmes have also been delivered at scale, again by public authorities and notably through Occupational Therapy services. Crowell and Sokas (2020) for example demonstrate a falls prevention programme operating at municipal level. Local older people on low incomes could receive an assessment of their home, and nonstructural modifications up to $10,000 in value were made to remove hazards that could lead to falls. This programme was notably successful in reducing both fear of falling and the number of falls that occurred. It is one of few studies to focus on people with lower incomes. Another example of a falls prevention programme in Australia is evaluated in a trial by Steinberg et al. (2000). The programme of interventions included advice on and implementation of home modifications and was found to be effective in reducing falls over a year. Whilst the study demonstrates success in the programme, little detail is provided about the home modifications

provided. The evaluation of this falls programme succeeded in demonstrating that design modifications can be delivered at scale, though again, within a municipal programme.

This literature gives little insight into how scalability might work – simply illustrating that home design innovations can be implemented at scale. In their evaluation of housing alongside care and support developments in West Lothian, Scotland, Bowes and McColgan (2013) argued that the successfully scaled delivery, supported by smart technology implemented in newly built and retrofitted homes, was dependent on the local authority's approach to delivery. The approach included a system wide commitment to delivering a new model of care and support that emphasized capacity and ability of older people rather than a deficit model; an opportunity to invest in a new approach facilitated by a favorable policy context at the time and the needs of the locality; a focus on mainstreaming the new developments to be accessible to all local older people; and a local leadership committed to change. Limitations to scalability were identified as including wider issues of ageism that restricts older people's inclusion and social problems in the communities where older people live. However, whilst this study did consider some aspects of scalability, these remain in the context of a local municipal programme.

The review identified no literature that considered commercial aspects of design innovation for aging. This remains a significant gap, given the significance of housing markets, and the business considerations for designers, builders, and developers. In the UK for example, as previously noted, commercial housebuilders currently build around 80% of new housing provision (Statista, 2023) and researchers seeking to inform improvements in housing for older people cannot ignore this.

Local factors and inequalities

A further important gap in the literature is consideration of the diversity of older people. There is a noticeable absence of studies that focus on diverse ethnic populations. The review identified one small study of Korean Americans (Chung et al., 2017) and one other that took place in a Hispanic neighborhood (Brown et al., 2008). Socio-economic differences are rarely considered, though some of the studies of municipal programmes identify lower income populations especially those living in social housing. In general, however, the literature identified does not consider issues of housing poverty or housing affordability. Some researchers draw attention to issues of diversity, for example Feldwieser et al. (2016), in recognizing the limitations of their sample of people who used an accelerometer form of fall detection system, suggested that further research involving more

diverse populations is needed. Their sample is described as having "high technical commitment" and as being in good health, thus representing a rather small sub-group of older people.

Cost effectiveness

Costs analysis of any sort is rare in the literature identified, though some researchers identify it as a desirable next step (e.g., Tchalla et al., 2012). This confirms findings from our earlier review focused on the costs of designs for dementia (Koreki et al., 2021). Furthermore, as noted, discussion of commercial considerations that may affect business involvement in home design is absent.

Several researchers provide an indication of the costs of the interventions evaluated, though remain unclear on how these have been calculated, whether they include the staff time involved or whether they are simply prices for equipment. For example, Interventions are frequently described as "low cost." Examples include Hunter et al. (2021) who describe the sensors used in their study as "low cost" and Steinberg et al. (2000) who refer to "low cost" of interventions including training and home modifications to prevent falls. Others give prices, for example, Stark et al. (2009) who recorded the costs of the items of equipment, installation costs and materials used. They calculate the average cost of the changes made at $159 per issue faced by the person concerned (at 2003 prices). However, they caution that these calculations may be context-specific (to the USA) and could vary with different health and social care systems. In this study, modifications involved the provision of equipment within the home, such as bathing aids, lamps, grabbers, and phone amplification. Notably, the authors do not provide a full cost-benefit analysis. In another study, Stark et al. (2018) calculated the cost of materials and installation of equipment to be a mean of $931 per person. Again, this was not a full economic evaluation: for example, whilst therapist time was itemized, it was not included in the cost calculations. Gitlin et al. (2006) identify a mean intervention cost of $1,222, including devices, delivery, installation and professional support costs: similarly a full cost benefit evaluation is not included in this study.

Jachan et al.'s (2021) German study provides additional information on costs of using smart technology and mobility aids in people's own homes. Their cost-benefit analysis considered the costs of the devices in relation to the benefits reported by the study participants, generating a price-performance ratio. The items included ranged in cost from €36 (for electrical sockets) to €2630 for lighting controls. They draw positive conclusions regarding the benefits for tenants, emphasizing that these need to be

understood in the context of policies favoring aging in place, and that issues of who pays remain to be resolved with the health insurance funds. This small study is helpful in identifying relevant considerations of costs but can draw only tentative conclusions as the sample was small, with 37 people in the intervention group and 64 in the control group.

Conclusions and implications for further research

Given the limited quality and coverage of the literature identified, it is possible to draw only tentative conclusions from the review. However, these conclusions are instructive for further research.

The outcomes identified in the literature were varied. Our discussion suggested that appropriate outcomes require an understanding of context, a holistic perspective and, particularly, can benefit from consultation with older people themselves regarding their preferences and aspirations. The need for consultation was also supported by literature identifying promising practice, that highlighted the importance of innovations that can cater for individual situations and preferences, thus responding to some extent to diversity among older people, a generally neglected aspect. There was little discussion of issues of scaling innovations or of delivering them in a business context. A small number of evaluations did consider programmes that had been implemented at scale, but these were all publicly funded initiatives. Whilst many studies noted the desirability of cost effectiveness or cost-benefit analysis, almost none accomplished these.

Thus, the review has identified several significant research gaps. Further exploration of older people's own diverse perspectives is merited, and several studies suggested that this would improve the appropriateness and acceptability of design innovations. There is a need for better understanding of effective practice in delivering design innovations and to understand the impact of contextual influences on effectiveness. The notable lack of consideration of scalability and the failure to explore commercial delivery of design innovations suggest a pressing need for further research that looks beyond the narrow focus of public services provision.

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