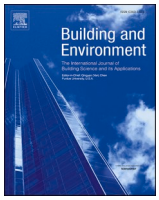
Building and Environment 274 (2025) 112742

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv



Ten questions concerning older people and a sustainable built environment

J. van Hoof [a,b,*], V. Soebarto [c], L. Ayalon [d], H.R. Marston [e], K.K. Zander [f], J. Dikken [a,g], J.K. Kazak [a,b]

[a] Research Group of Urban Ageing, Faculty of Social Work & Education, The Hague University of Applied Sciences, Johanna Westerdijkplein 75, 2521 EN Den Haag, the Netherlands
[b] Department of Systems Research, Faculty of Spatial Management and Landscape Architecture, Wrocław University of Environmental and Life Sciences, ul. Grunwaldzka 55, 50-357, Wrocław, Poland
[c] School of Architecture and Civil Engineering, The University of Adelaide, North Terrace, Adelaide, SA, 5005, Australia
[d] Louis and Gabi Weisfeld School of Social Work, Faculty of Social Sciences, Bar-Ilan University, Max and Anna Web, Ramat Gan, Israel
[e] School of Health, Wellbeing and Social Care, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK
[f] Northern Institute, Charles Darwin University, Ellengowan Drive, Darwin, 0909 NT, Australia
[g] Faculty of Health, Nutrition & Sport, The Hague University of Applied Sciences, Johanna Westerdijkplein 75, 2521 EN Den Haag, the Netherlands

ARTICLE INFO

Keywords:
Older adults
Built environment
Environmental sustainability
Housing
Review
Overview

ABSTRACT

Around the globe environmental sustainability of the built environment has become a pressing issue for everyday life. Environmental sustainability is defined as a state where natural ecosystems and resources are preserved to support the well-being of the present as well as future generations. Environmental sustainability requires the carbon emissions from the built environment to be minimised and air quality to be improved. This is a relevant topic for people of all ages, with older people recognised as key contributors to shaping a better world for future generations. Older people will also benefit from any environmentally sustainable practices since many of them improve comfort and lower energy use. Further, in the long-term, implementing environmentally sustainable practices will help reduce the cost of utilities, making it more affordable for older people to live in their homes comfortably. This 'Ten Questions contribution' provides an overview of the importance of environmental sustainability in the built environment for older people, what it constitutes, how it can be evaluated and stimulated, the barriers to implementing environmentally sustainable solutions, as well as policies and future perspectives to achieve environmental sustainability.

1. Introduction

As societies around the globe are ageing, it is important to develop and increase understanding of the diverse perspectives and behaviours of older people regarding a sustainable built environment in which we live. Sustainability encompasses environmental, economic and social sustainability [1–3], which revolves around meeting the need of the present generation while maintaining the prospects of the future.

Contemporary gerontological literature employs a life course perspective in scholarly research [4,5]. Yet, Laslett [6] categorised life through four phases: first, second, third and fourth ages, whereby the second age is seen as the phase of life of productivity, employed with an income, and actively engaged, including marriage, relationships, starting a family, owning or renting a property. The third age is perceived as the 'retirement phase' of one's life, with increased opportunities for personal development and forming new social relationships [7] while the fourth age is perceived as "a new dependency period and the last part of old age where there is no hope for living in the course of life before death" [8]. Vincent [7] describes how age in Western societies can be categorised through institutional and bureaucratic procedures, structured around the modern working life [pp. 9–12]. Vincent describes how the notion of

> "*retaining the integrity of the idea of the third age, social gerontologists invented the fourth age – namely a further period of life after pre-work, work, post-work – ad constitutes a final stages of dependency. Thus, despite many benefits, the third-age formula does not overcome the problem of old age; it merely postpones it.*" [7], p. 167].

* Corresponding author.
E-mail addresses: j.vanhoof@hhs.nl (J. van Hoof), veronica.soebarto@adelaide.edu.au (V. Soebarto), liat.ayalon@biu.ac.il (L. Ayalon), Hannah.Marston@open.ac.uk (H.R. Marston), Kerstin.Zander@cdu.edu.au (K.K. Zander), j.dikken@hhs.nl (J. Dikken), jan.kazak@upwr.edu.pl (J.K. Kazak).

https://doi.org/10.1016/j.buildenv.2025.112742
Received 28 November 2024; Received in revised form 8 February 2025; Accepted 15 February 2025
Available online 17 February 2025

In this context, we would categorise people in the second and third stages of their life as being key users of energy efficiency technologies, although the cost-of-living crises [9] have impacted the daily activities of people across the life course, and many people in the second age, although employed, may not have the financial resources to afford energy efficient technologies. Vincent [7], p.17], too, highlights the generational differences of financial resources in the latter part of the twentieth century noting how " *[T]here is evidence to show that in Britain there is a growing number of old people who are significantly more affluent than was typical a generation ago*. Yet, the term older people is used as a means of removing ageist terminology [10], aligning with the World Health Organization [11] (2021) decade plan of action to combat ageism, together with the United Nations Decade of Healthy Ageing (2021–2030].

In practice, the term 'older adults' refer to those who enter retirement age, which may vary from country to country. In the United Kingdom the Welsh Government considers people aged 50 years and over as older people [12]. In some countries, older adults are considered those aged 60 years and over, while in other countries, the starting age to be considered 'older adults' is 65 years old. It should be noted that although they fall into the third age group according to Vincent [7], many of those considered "older adults" are still employed with an income, thus they may still be considered as part of the second age group. Therefore, we support the argument of employing a life course approach [13], together with collective terms such as older or younger adults, because they reduce the need to specifically outline country specific legislation and affords a collective language approach.

Given the emergence of global action programmes that promote sustainable development and efforts to mitigate climate change through a reduced level of greenhouse gas emissions [14], older people cannot be a passive cohort in society who only depends on the younger generations to come to action. On the contrary, older people are expected to deliver their fair share. In fact, many older people have already been actively or unknowingly involved in sustainable practices, ranging from insulating their homes, switching thermostats to a lower set-point temperature in winter, to buying energy-efficient appliances [15–17]. Although some of these actions are not entirely driven by 'green motives', as financial stimuli may also be at play, the end-result is positive from an environmental point of view [18].

In the previous quarter of a century, the interplay of ageing societies and sustainable development were explored by scholars such as Pillemer et al. [19] and Wright and Lund [20]. A more recent pan-European study by Dikken et al. [18] identified several typologies of older people that can be distinguished based on behavioural drivers, one's financial position and beliefs concerning environmental sustainability. Such typologies can be important corner stones and building blocks for future policies targeted at sustainable development and climate change actions by older people [21]. The need to actively target older people as actors in sustainable development becomes even more relevant due to the longer life expectancy of older people today. Longer life expectancies imply that any actions taken by older people will have a long-term effect.

In 2024, the WHO [22] launched a report "*Making older persons visible in the Sustainable Development Goals' monitoring framework and indicators*", in which an explicit connection is made between population ageing and the sustainable development goals (SDGs). A total of 15 out of 17 SDGs are believed to be relevant for older people and population ageing [22,23] and older people need to work together with all levels of civil society, and vice versa, to achieve these goals. The WHO [22], p. xii] states that "*In order to reach older people – an important, heterogeneous and growing population […], a closer examination is needed of the kinds of data collection mechanisms and methods, and types of data collected to measure each SDG indicator relevant for older persons.*" It is further narrated that the SDGs do not have a specific focus on older people, and that plain and coherent guidance on how to monitor progress for older people is missing. To add to the case, the WHO posits that sustainable "*actions should improve the lives and opportunities of people at each life stage, to develop optimally and reach their potential, as well as accumulate benefits supporting each subsequent life stage, including older age*" [22], p.14]. The relationship between the SDGs and the age-friendly cities' movement has been described and elaborated in various sources, including WHO [23], van Hoof et al. [24], and Dabelko-Schoeny et al. [25]. As stated by Dikken et al. [18] the convergence of the WHO's agenda for age-friendly cities and communities and sustainable development underscores the interdisciplinary nature of sustainability and the complex interplay of various actors in this domain.

This is a tangible proof that older people are considered important actors in improving the world we leave for future generations. With this in mind, the main theme of these Ten Questions [26] contribution is: What can older people do in terms of environmental sustainability in the built environment? This pertinent question leads to a cascade of related questions as discussed below. It is important to state that in this Ten Questions contribution, we mainly focus on older people living in high-income and upper-middle-income countries, where policy and practice concerning a sustainable built environment in which we live are the most advanced.

1.1. Structure of the paper

Section 2 addresses ten questions about older people and environmental sustainability in the built environment. This section is structured as follows. First, we explore the background of older people and sustainable built environments including their perceptions and motivation as well as similarities and differences between younger and older cohorts. This is an introduction to specific elements of older people in our society in comparison to other (i.e., younger) age groups, and the specific motivating factors for their sustainable perceptions and practices. Second, we look at the measurements and assessments of sustainable behaviours as well as challenges and barriers that may be encountered by older people to achieve sustainable built environments. Being able to assess such behaviours in a quantitative way helps to identify the challenges and barriers that can be taken away as well as the opportunities and potential benefits that can be improved. Third, we discuss relevant phenomena and activities that impact how older people lead more sustainable lives, including in the context of the socio-economic debate on energy poverty, and at home in a general sense. This discussion is broadened in the light of the political and societal debates of the impacts of climate change on older people and their roles in mitigating the effects thereof. Fourth, we look at the role of technology and future actions by older people themselves. This section is driven by technological innovations that can become future trends in assisting older people to live more sustainable lives. It also proposes some vision and recommendations for future actions and research.

The questions are presented according to the following thematic structure:

- Background (Q1, Q2);
- Measurement, challenges, barriers, opportunities and benefits (Q3, Q4; Q5);
- Energy poverty, leading a sustainable life and climate change (Q6, Q7, Q8);
- Future perspectives, including technology and recommendations for future research and actions (Q9, Q10).

2. Ten questions (and answers) concerning older people and a sustainable built environment

2.1. *"Question 1: How do older people perceive environmental sustainability and what factors motivate sustainable practices among older people?"*

Answer: Many studies have explored the perceptions of

environmental sustainability of older people, mostly in high-income and upper-middle-income countries [15,27–29] and perception and choices older people make on their purchase of consumer goods in relation to the environmental impacts [30]. In a representative field survey among community-dwelling older people conducted in The Hague in 2022, van Hoof and Dikken et al. [178] explored how older people in the Netherlands perceive environmental sustainability, particularly in the context of the built environment. The study identified a wide range of attitudes and motivations as well as concrete actions they undertook to lead a more sustainable lifestyle. Nonetheless, while these Dutch findings offer a valuable quantitative insight on how older people relate to the topic of environmental sustainability, it is predicted that findings from Dutch older citizens may be different from those living in other countries, partially because of variations in cultural norms, socio-economic contexts, and national political priorities [18]. An international study by Dikken et al. [18,32]conducted among older people in Poland, North Macedonia, the Netherlands, Romania and Israel further shows differences in attitudes and perceptions due to variances in the cultural, political and economic histories and realities. According to Dikken et al. [32], factors such as one's financial position, beliefs and pro-environmental behaviours influence the motivation to live a sustainable lifestyle in older age in all of the countries but there is also a uniqueness in each country. For instance, sustainable behaviours of older people in Eastern Europe are governed by the same factors as those of older people in the Netherlands but the underlying mechanisms and elements are different [32]. The higher the level of economic development and one's personal purchasing power, the greater older people seem to be consciously engaging in sustainable practices, driven by beliefs and enabled through one's financial position [32]. Based on a multi-centre study comprising 2318 respondents, Dikken et al. [18] identify four unique and distinct European typologies and their drivers for, and contributions to, sustainable practices. These typologies are: (1) inactive people with limited financial resources, (2) inactive believers, (3) active and belief-driven people with limited financial resources and (4) active and belief-driven people with financial resources. Aslanoğlu et al. [33] provided further insights into the complex interrelationships between financial situations, pro-environmental beliefs, and behaviours of older adults, demonstrating the importance of tailoring sustainability interventions to the unique profiles of this demographic. However, the successful implementation of such broadly designed interventions requires careful consideration of individual financial and social contexts to enhance their effectiveness.

Apart from the typologies mentioned above, we know from scientific literature that personality characteristics are associated with the likelihood to engage in sustainable behaviours. Both agreeableness (which represents a personality trait of empathy and compassion) and openness to experiences (which represents cognitive flexibility) are associated with a greater motivation to live sustainable life. These personality characteristics are also predictors of sustainable living when evaluated aggregately at the national level [34]. Other cultural values have also been shown to contribute to sustainable behaviours, including collectivism, feminism, future orientation, and uncertainty avoidance [35].

2.2. *"Question 2: What similarities and differences exist between older people and younger cohorts in their sustainability perceptions and practices?"*

Answer: A comprehensive meta-analysis of studies published between 1970 and 2010 concluded that there are minimal differences between older and younger people in their behaviours towards the environment. Both groups are rather similar. However, small differences between the age groups have indicated that it is the older rather than younger people who are more likely to engage with nature, avoid environmental harm and engage in conservation Wiernik et al. [36]. This is despite the fact that older people are less likely to indicate that climate change is real and caused by humans [37]. Hence, it seems that what motivates a more sustainable lifestyle among older people is their preexisting habits rather than intentional motivations to engage in environmental sustainability. It is also possible that the differences represent generational rather than age differences.

In a 'social and eco-conscious justice' way, Pillemer and Wagenet [38], p. 6021 went as far to write that "*today's [older people] must come to feel an obligation to future generations. […] we are now called to join with other generations to safeguard the world for our successors.*" Boluda-Verdú et al [39] found that younger people are more concerned about climate change; however, they are less likely to engage in pro-environmental behaviours [40] compared to older people.

A scoping review by Ayalon et al. [41] has built the case for more intergenerational cooperation with both younger and older cohorts working together in actions geared towards mitigation. A study from Poland [42] shows that older people demonstrate high emotional engagement with the issue of climate change; however, age may not be the only determining factor here as pro-environmental behaviours can also be impacted by gender and educational levels including sustainability literacy [27,40,43–45].

Apart from intergenerational approaches that connect and unite people across age-cohorts, there are also more divisive movements in society, some of which are driven by ageism. Across Europe, there have been discussions if older people should even be allowed to vote about issues in the future which will not affect them personally, as on average older voters vote differently from younger cohorts [46]. For instance, as measures to mitigate climate change will become evident in decades to come, older people were blamed by opinion makers and politicians in the Netherlands, Italy and the United Kingdom for not taking the needs of younger people in consideration [46]. Some Dutch opinion makers went as far as to say that voting rights should be limited or taken away after a certain age, even though this is a blatant violation to the rule of law [46].

To some extent, these opinions are ageist as they arbitrarily categorise and assign value to individuals based on their chronological age [47]. This arbitrary division between young and old results in tension and conflict between the generations. Past research has shown that conflict between groups often is a result of perceived realistic and values, beliefs and norms. Realistic threats relate to concrete real-life resources that are in scarcity, whereas symbolic threats relate to discrepancies in values and perceived sources of power. In the case of engagement in sustainable practices, both threats may hamper the relationship between the generations [48].

2.3. *"Question 3: How can sustainable practices among older people be measured and assessed?"*

Answer: In recent decades, a growing body of studies on older people and sustainability has been published widely [15]. Many of the studies presented were the result of qualitative enquiries, employing interviews and focus groups to study older people's view of sustainability and their actions. Much of the work stems from the domain of social sciences or architectural and environmental sciences. Apart from these qualitative approaches, a plethora of quantitative measurement scales have been developed and validated to assess pro-environmental attitudes and behaviours to promote sustainable development in society [49,50]. From a psychometric perspective, however, the robustness and validity of many of these tools are still questionable as they have not been developed using standardised protocols used in the scientific disciplines of psychometrics or clinimetrics. Existing scales such as the Pro-Environmental Attitudes Questionnaire (PEAQ) [51] and the Environmental Awareness Scale [52], to name only two out of many, can be used to measure environmental attitudes and behaviours of adults in general but such instruments do not particularly focus on older people. Several aspects of questionnaire development can go wrong or are often not transparently described, which makes any developed tool difficult to use and limits its generalisability.

Adherence to rigorous development and validation protocols, as outlined in frameworks like the COSMIN criteria (COnsensus-based Standards for the selection of health Measurement INstruments), is essential to ensure a questionnaire's reliability, validity, and applicability across different contexts and populations [53]. These criteria highlight potential issues, including insufficient content validity, lack of cross-cultural applicability, poor reliability, unclear structural validity, and failure to test measurement invariance across groups. Moreover, the responsiveness and interpretability of scores often remain unexplored, making longitudinal applications challenging. If these aspects are neglected, especially in cross-cultural research or among underrepresented groups such as older adults, the tools' relevance and usability are significantly diminished. For instance, scales like PEAQ may lack items tailored to the unique environmental attitudes and behaviours of older populations, but it remains unproven that their constructs translate effectively across cultural contexts. To address these challenges, Dikken et al. [54] undertook the process of developing a standardised and validated instrument that can be used to measure how older people think about the concept of environmental sustainability, resulting in the SustainABLE-16 Questionnaire. The development of the instrument showed that views on sustainability among older people are mainly governed by their "Financial position", "Pro-environmental behaviours" and "Beliefs" [54]. Because transparency and adherence to the COSMIN protocol were key principles from the onset, this scale is particularly useful for making cross-cultural comparisons. In 2024, Dikken et al. [32] validated the SustainABLE-16 using a cross-cultural approach, which led to the successful validation of a shorter SustainABLE-8 questionnaire. This multi-country study used large-scale datasets gathered in surveys conducted with older citizens living in Poland, North Macedonia, Romania and Israel. The SustainABLE-8 encompasses eight items on energy conservation, concerns about climate change and attitudes towards renewable energy use within three domains, namely the aforementioned "Financial position", "Pro-environmental behaviours" and "Beliefs".

However, the SustainABLE-16 Questionnaire is not without limitations. With only 16 questions, it is unlikely the SustainABLE-16 fully captures the complexity of large constructs such as behaviours and beliefs. Consequently, this instrument should be seen as a way to collect numeric data, offering a first impression, helping to generalise results and compare these between cities, regions and even countries. However, as with most quantitative instruments, it is advisable to complement data from questionnaires with additional qualitative research for more in-depth insights. For instance, methods such as in-depth interviews can uncover the nuanced personal motivations and barriers related to pro-environmental behaviours. Focus groups may reveal diverse cultural or social interpretations of sustainability, and ethnographic studies could provide rich contextual data on how sustainability is experienced and practiced in everyday life. By integrating such approaches, using the SustainABLE-16 for a broader picture of sustainability perceptions among older adults and qualitative data collection for in depth insights, the complex factors influencing sustainable practices among older people can be more comprehensively understood.

Regardless of the evaluation of beliefs and behaviours of older adults toward sustainability through surveys and questionnaires, there exists another dimension for assessing human activity and its impact on the state of the environment. To claim that human activity operates within boundaries of sustainability, its resource consumption should not exceed the limits provided by the planet. Two of the most widely used metrics for evaluating these aspects are the ecological footprint (alternatively carbon footprint, as this value accounts for the majority of the share in the ecological footprint), representing the effects of resource consumption [55], and biocapacity, which measures the available resources. Only when we consume fewer environmental resources than we possess, leaving a buffer to allow nature to regenerate these resources for the future, can we assert that we operate within the sphere of environmental carrying capacity [56]. This concept has become one of the key frameworks for evaluating carbon emissions. The balance—between what we have and what we consume—helps illustrate the areas where we remain within the planet's capacities and where planetary boundaries have already been exceeded [57]. The ecological footprint is influenced by all key aspects of human functioning, such as where we live, the size of our homes, how much energy and water we use, the amount of waste we generate, our dietary habits, how and how much we travel within the city, and the quantity of everyday items we purchase. To measure sustainable practices among older adults specifically, existing tools often include indicators related to their household energy use, waste reduction behaviours, and transportation choices. For instance, questions may assess the frequency of using public transport, efforts to recycle, or preferences for energy-efficient appliances. These items aim to provide insights into how older adults integrate sustainability into their daily lives.

Our daily choices drive demand and, consequently, influence changes in the global resource management system. Thus, even by altering everyday consumer habits, we can contribute to reducing environmental pressure [58]. As evidenced by situations that have forced entire societies to change their behaviour patterns, it is possible to adopt alternative ways of functioning that reduce carbon emissions in the built environment and improve air quality [59].

The ecological footprint is a metric that has been specifically applied to assess the older part of society, adapting measurement methods to the consumption habits of this demographic cohort [60]. Interestingly, a comparison of the individual carbon footprint of individuals aged 65 and older with that of younger people reveals that older adults have a lower footprint. Similar results were observed in measurements focused specifically on energy consumption [61]. By examining both global metrics, which reflect the transgression of environmental sustainability thresholds, and local metrics, which characterise societal functioning worldwide, it becomes possible to identify key areas where public actions should focus to support more sustainable policies.

2.4. *"Question 4: What are the challenges and barriers for older people to achieve sustainability?"*

Answer: The challenges for older people to achieve or be involved in any efforts to achieve sustainability occur at two levels: at the society level and at the individual level. At the society level, first and foremost, older people are often perceived as a single homogenous group in terms of their capacity, values and resources [62] where in fact they are quite heterogeneous in terms of their biological age, functional and health status as well as socio-economic status [31,63]. For example, while some older people are active actors in resource conservation and environmental protection [64] and possess sustainability literacy [27], others could become less interested in acquiring environmental knowledge and in participating in sustainable behaviours as they found sustainable ideas and actions to be disruptive [36]. Perceiving older people as one homogenous group can lead to policies, guidelines, strategies and efforts that may only be relevant for some older people but not all, resulting in only a portion of the older people population actively participating in environmental sustainability.

Shared beliefs may also affect older people's behaviour towards the environment and how they can achieve environmental sustainability [65]. For example, many Javanese people in Indonesia believe in ghosts, magic and the supernatural [66], which are believed to occur in, or be associated with, darkness. It is, therefore, uncommon for older people in Java to not extinguish the lights while they are sleeping because lighting is perceived to provide security and can deter bad spirits, as pointed out by Bruce [66]. From the environmental sustainability point of view, leaving the lights on at night is a waste of electricity and can increase greenhouse gas emission; however, changing the belief and practice of these people is obviously challenging.

At the individual level, the financial situation of each older person can significantly influence their environmental attitude, behaviour and

decision to be an active participant in achieving environmental sustainability. For those with financial constraints particularly those living in energy poverty, meeting the basic needs -food and accommodation – is the most important goal before they can even start to think about environmental sustainability [67]. At the same time, as they have limited household income, they also tend to use less energy for heating or cooling, though this may also mean that they live in dwellings with poor indoor environmental quality [68–70]. Thus, while it appears that low-income older people make less negative impact on environmental sustainability, this occurs out of financial necessity and constraints (which may actually impact on their health and well-being negatively) rather than out of environmental awareness and considerations.

On the opposite side, studies found that those older people who are financially secure in developed countries have the highest per capita carbon footprint particularly from heating their homes compared to the other age groups in the population [71]. Studies conducted in many countries including Indonesia, Japan, Australia and the United States found that many older people are unwilling to sacrifice part of their income for a cleaner environment [72–74] and continue to consume more energy (per person) compared to those who are less wealthy.

Another challenge at the individual level relates to older people's physical conditions and health status. Reduced physical health often forces them to stay indoor most of the time, resulting in them using more energy to run heating, cooling, lighting and appliances in their homes [75]. The tendency to use more energy for heating and cooling can be further exacerbated with increasing occurrences of extreme temperatures in recent years, which are expected to continue in the coming years [76].

Increased reliance on air-conditioners could also relate to poor outdoor air quality. Data from a survey of more than 13,000 older people in China in 2018 showed a strong association between the distance of their dwellings from major roadways and individuals exposed to carbon monoxide pollution or the frequency of opening a window [77]. Likewise, in highly populated areas, noise pollution (traffic, people outside) has also been found to be significantly correlated with windows being closed [78]. Both situations can force older people to use air-conditioners more frequently.

Another main challenge for many older people to achieve environmental sustainability is the quality of their own homes. A study conducted in South Australia showed that most older people surveyed lived in dwellings that were more than 20 years old [79]. This means their houses did not necessarily comply with the energy-efficiency provision of the Australian National Construction Code, launched in 2003. Further investigations revealed that the indoor temperature in many of the houses was as low as 12°C in winter and up to 33°C in summer when heating or cooling was not in use [80]. If these homes were to be air-conditioned, it is likely that they would consume a lot of energy due to their poor quality.

Overcoming the challenges discussed above will help achieve environmental sustainability for older people; however, some barriers exist. For example, while guidelines for public spaces and buildings in many cities have been informed by the World Health Organization's "*Global Age-friendly Cities: A Guide*" [81] that recognise different conditions of physical abilities of older people as well as their economic, social and cultural backgrounds, they do not necessarily address differences among older people in terms of their living arrangement, health and well-being status, frailty levels, preferences, environmental attitudes, and even access to information and technologies. A new study by Soebarto et al. [82] finds that frailty levels significantly affect older people's thermal comfort and behaviours and need to be considered when developing guidelines and standards that will affect the living environment of older people. More critically, building codes that aim to achieve environmental sustainability still do not have specific considerations about older people who will use the building, except in buildings specifically designed for older people, i.e., residential aged care buildings. Assumptions embedded in building performance assessment tools also do not take into considerations that they may not be relevant for older people. For example, in Australia, the Nationwide Home Energy Rating Scheme (NatHERS), a scheme used to rate the energy-efficiency of new residential building designs, assumes that windows will be opened and closed at certain times of the day or year, depending on the indoor and outdoor conditions. In reality, older people do not always want to, or able to, open and close the windows [82] due to the difficulties in opening or closing them. Assuming that the older occupants will open and close windows in the same way the general population would do may result in design guidelines or building designs that not only are unsuitable for older people but may also use more energy than predicted, hindering the success of achieving environmental sustainability.

2.5. *"Question 5: What are the opportunities and potential benefits for older people to achieve sustainability?"*

Answer: Older people have a lot of opportunities to achieve sustainability in their home living environments, in their neighbourhood and for the society at large. In their own home, older people can achieve environmental sustainability by implementing strategies that will help minimise their energy consumption, reduce waste, conserve water and increase biodiversity. In their neighbourhood, older people can also contribute to achieving both environmental and social sustainability.

First, it is important for older people to live in an indoor environment with a thermal condition that is conducive to their health – not too cold and not too hot [83–87]. Achieving such a condition can be done in ways that are not necessarily consuming a large amount of energy and requiring high investments. For example, to reduce air leaks around the house that can result in heat loss and increase the need for heating, weather stripping can be applied (for instance, around window and door frames). Such low-cost action can have a significant impact on thermal comfort and energy use (such as, Soebarto et al. [88]). Simple actions such as opening and closing windows and blinds at the right time or adding external shading can help reduce the likelihood of the house becoming too cold or too hot, and, therefore, minimise the need to run the air-conditioner either for heating or cooling. If using air-conditioners is unavoidable, then energy-efficient heating and cooling appliances must be used over old, inefficient systems [88]. Finally, older people will also be able to reduce their greenhouse gas production by adopting renewable energy and smart technologies such as solar panels and solar water heating.

Second, older people can contribute to the efforts of waste minimisation by reusing goods instead of always purchasing new ones and throwing away the old ones, recycling, and separating different types of household-wastes their produce, i.e., general, green, and recyclable wastes. Some older people have been practising these actions for years, potentially shaped by hardships in their upbringing [61]. However, such actions can only be implemented if the local municipality provides the services for householders to do so. Finally, downsizing homes is another way older people could contribute to sustainability, but this step is often met with challenges, resulting in only a small proportion making this move [89].

Third, conserving water can be done by replacing old fixtures, such as showerheads, toilet flush and water faucets, with the more water-efficient ones. Collecting and using rainwater is also another way that older people can do to minimise their water consumption. Finally, older people can help improve environmental sustainability by increasing biodiversity. Planting various types of plants at home or volunteering to help maintain the green spaces around the neighbourhood can all contribute to improving biodiversity. Many older people already engage in nature-based activities and are keen to maintain the status-quo of an intact environment. They recognise the importance of adopting pro-environmental behaviours to achieve this [90]. Nonetheless, some older people may lack the enthusiasm to take environmental-related actions because they perceive these actions to be irrelevant to them [36]. While this is a challenge, it should at the same time provide

relevant agencies with an opportunity to think about ways to make those older people see that the actions are indeed very relevant to them.

Studies have also shown that many older people are willing to be involved in environmental volunteering activities when these would give them opportunities to be outdoors and have social interactions [91]. Involving them in such activities will also help those older people who are sceptical to see that achieving environmental sustainability benefits their individual lives. Likewise, another way to encourage older people to become enthusiastic about environmental actions is by involving them in the dialogues about the environment instead of simply treating them as passive receivers of information. Encouraging older people to be engaged in the community through such activities means that they also contribute to social sustainability. This approach will be discussed later in answering Question 7.

Contributing to achieve sustainability provides many benefits to older people. In relation to efforts to achieve environmental sustainability as discussed above, reducing energy consumption while achieving thermal comfort will result in reducing the energy bills and saving their money. Those who can afford to install solar panels can further benefit from long-term cost savings in paying for their electricity usage. Further to this economic benefit, maintaining indoor temperatures and humidity at the levels that are considered thermally comfortable by the occupants also improve and maintain their health. A study reported by Hansen et al. [80] also shows that well-being, particularly having a good mood and satisfaction with the living environment, occurs when the indoor temperature can be maintained between 15 and 28°C. Moreover, living in a less leaky home but also having fresh air when they need it through adequate ventilation will improve the indoor air quality, which in turn will improve or maintain their health [92].

Having access and connection to greenspace, either only visually or also physically, has been shown to link to improved health and well-being particularly among older people [93,94]. Trees provide shade, and together with other types of greenery in the neighbourhood and around the house, they help cool the outdoor air, which is particularly important during the summer, which consequently can also reduce the need for air-conditioning at home [95,96]. Biodiversity in the neighbourhood and around the house will positively impact older occupants' health and well-being as biodiversity has been shown to link to increased happiness, enhance restorative benefits and improve emotional well-being [97,98].

In summary, older people will have direct benefits from engaging in activities to achieve environmental sustainability within their own living environment and neighbourhood. These include health benefits from living in homes with better indoor and outdoor environmental quality, economic benefits from reduced use of heating and cooling, and increased happiness as well as improved health and emotional well-being from having greener, cooler and more biodiverse neighbourhood. Engaging older people in environmentally sustainable activities and education will empower them and increase their engagement in society which in turn will benefit society as a whole [99,100].

2.6. *"Question 6: What is energy poverty and how does this impede the sustainable lives of older people?"*

Answer: Energy poverty, often referred to as fuel poverty, is the condition of being unable to financially afford to keep one's home adequately heated [101]. Many countries have their own definition of energy poverty, and even within countries (such as the United Kingdom, various differences exist [102]. Energy poverty can be measured using an affordability metric, namely if a household's required energy costs are at least a certain percentage of a household's income before housing costs, that household can be classed as energy poor. Such a definition can include the cost of cooling (in warmer climates), for instance, in countries like Spain, Australia and Greece, and use of electrical appliances. It is, thus, not necessarily about heating per se.

The phenomenon of energy poverty is not new [103]. Back in 1987, Avery and Pestle [104] wrote about hypothermia and older people, stating that many low-income older people were particularly vulnerable to cold weather conditions as they often lived in poorly insulated dwellings, have limited access to adequate heating systems and in some cases even lacked appropriate clothing and bedding. In many studies that deal with older people living in energy poverty, the implications of high energy costs on the daily lives have been described in great detail. The story is literally choosing between heating or eating. Although the link with sustainability was not made in these early studies, one could argue that cost-awareness led to an austere lifestyle among the people studied [18].

Nonetheless, the energy and cost-of-living crisis have worsened since mid-2021, which was aggravated by the invasion of Ukraine by Russia, raising the awareness among politicians and the general population that a growing share of the older population, particularly in Europe, has a great difficulty to afford their energy bills particularly for heating in the winter [17]. A disproportionate share of older people's disposable income is used to pay the heating bills, and many countries in Europe have introduced a (temporary) form of financial relief, including the United Kingdom and the Netherlands. It is partly with this in mind, that all across the European continent thermal retrofitting of dwellings for older people is underway to reduce the share of one's disposable income spent on energy [101].

Reducing the overall energy use in older households has once again received increased attention in research, both from an energy poverty as well as from a sustainability viewpoint [18]. Van Hoof [17] describes how the scholarly research on climate change mitigation, environmental sustainability, energy efficiency of buildings and the impacts of energy poverty come together. Based on the insights gained in the research to improve the thermal environment of housing of older people in South Australia [80,105], Arakawa Martins et al. [106] reverted to the use of building performance simulation to explore strategies to achieve thermal comfort while limiting energy use in homes of older people. Nonetheless, studies to address energy poverty should not be solely focused on heating and cooling systems but also on other factors, such as lighting and household appliances [107,108].

Conversely, one could also speak of energy affluence, and it is expected that this has an opposite effect as energy poverty. A study from urban China by Zhu and Lin [109] studied the effect of retirement on the electricity consumption of the older people in the period 2010–2018. It was found that retirement increases household electricity consumption by 20 to 32 %. Moreover, this effect was more significant among residents with higher incomes, higher education levels and good health. Thus, higher income levels went together with higher levels of energy use. This is also reflected in the studies by van Hoof and Dikken [31] and Dikken et al. [18], in which typologies were developed based on large field studies in the Netherlands and across Europe. People who lived in better financial conditions could on the one hand invest in solar panels, home insulation and other types of sustainable measures. At the same time, we know that their overall energy consumption patterns are different (i.e., higher energy use) than that of people living with financial constraints, and also the type of homes are different (more often a (semi-) detached home).

2.7. *"Question 7: How can older people lead more sustainable lives in the places they live?"*

Answer: There are many things that communities and older people can do to address issues concerning environmental sustainability, whether this is in their own homes, in retirement housing and in institutional settings. Solutions to live a more sustainable life range from making changes in daily routines, consumption patterns to making improvements to the built environment particularly their home [27,110,111]. There are also so-called frugal solutions that people can implement, which are low-cost and easy to implement, including closing

curtains in winter, lowering the set-point temperature of the heating system in winter or increasing the cooling set-point temperature in summer, and wearing the appropriate clothing for the season [110].

Many older people have led sustainable lives without necessarily calling it 'sustainable'. Particularly in relation to dealing with the thermal environment – to be cooler during a hot day or to be warmer in a cold day – older people have employed many strategies that have little adverse impacts on the environment, either based on past experiences or learned knowledge, environmental beliefs or financial constraints [112]. For example, many older South Australians in the study by van Hoof et al. [112] grew up at the time when air-conditioners were rarely available or used. To be thermally comfortable they applied "low environmental impact" strategies, such as changing their clothing layers and activity levels, and adjusting their diets such as eating warm food during the winter or consuming cold drinks during the summer. At the most, they would use ceiling or pedestal fans to feel cooler, which use very little electricity and therefore will not have much environmental impact [112]. Many older people to date still apply the same strategies even though air-conditioners are now commonly installed at homes. Furthermore, lack of exposure to air-conditioning systems while growing up has made many older people dislike the air blown out of the air-conditioner and, therefore, they only use it occasionally [112]. Most older people in Australia also turn off the air-conditioner before they go to bed because that was what they used to do as they grew up, as highlighted in the studies by Williamson et al. [105] and Damiati [113]. Older people in Australia are also more likely not to use air-conditioning at all compared to the younger cohorts and if they use it, they put the set-point on higher temperatures than younger people [114]. All of these past experiences or learned (behaviour) knowledge affect older people's practices in operating their homes, which from an environmental sustainability point of view are actually 'quite sustainable'.

Some older people have led sustainable lives due to their environmental beliefs and concerns [31,112]. A recent study to assess environmental awareness and sustainable behaviour among older and younger groups in Poland and Germany finds that both groups exhibit environmental awareness and have practiced sustainable behaviours although with different focus [115]. Nonetheless, the study identifies that the younger group in Poland had in fact more limited understanding about ecological practices compared to the older group. This is not to say that all older people are environmentally conscious and, therefore, lead sustainable lifestyles. The study by van Hoof and Dikken [31] that investigated the mindsets among older people in The Hague about their built environment reveals that almost 40% of the 383 participants were in fact 'non-believers': either simply non-believers or financially driven non-believers. Both groups do not hold strong beliefs concerning the importance of sustainable development and climate change mitigation, and, therefore, are less keen to adopt sustainable lifestyle. Interestingly, the study finds that the financially driven non-believers may want to adopt a sustainable lifestyle if doing so would benefit their disposable incomes.

The influence of the financial situation of older people, or in fact on anyone, as to whether or not they would lead more sustainable lives can indeed be significant. For those with limited disposable incomes, living more sustainable as a means to minimise the household's energy consumption is not a matter of choice but a must. Soebarto et al. [79] found that the majority of the older participants in South Australia stated that the main reason for not using air-conditioners even when they needed them was to reduce their energy bills. Studies in other countries also show similar findings in China [116], the UK [117,118], Ireland [119], and New Zealand [120]. Although the main reason was financial, the side implication is environmental, because by not using air-conditioners they would reduce their environmental impacts. However, while from the environmental sustainability point of view this is a positive strategy, having an indoor thermal environment that is either too cold or too hot can have significantly negative impacts on the health and well-being of the occupants. On the other hand, if the financial factor becomes the goal or objective for sustainable development, then that is still a motivation that eventually leads towards a more sustainable future. For example, using more energy-efficient appliances, turning off the lights when not needed, or setting the air-conditioners' thermostat to moderate temperatures that are not too high in winter or too low in summer, would mean reducing not only the electricity use but also the costs [121].

For older people who have not yet adopted more sustainable lives in the places where they live, a few strategies can be implemented. The first one is by involving them in environmental volunteering activities as well as dialogues, which have been discussed above in answering Question 4. The next step is by providing clear information about the positive impact of doing so, not only on the environment and their finances, but also on their health and well-being. It should be noted, however, that the differences in older people's financial capabilities should inform the kind of guidelines or information provided to them. For example, the thermal comfort guide developed by Soebarto et al. [110] adopts a 3-step recommendation system to cater for the different financial capabilities and physical constraints of older people. For those who have very low budget whose mobility may also be constrained, the first suggestion to achieve thermal comfort in an environmentally sustainable way is for older people to, for example, vary their clothing layers and activity levels according to the season, or to eat hot meals or take hot drinks during cold weather (or taking cold food or drinks during hot weather). For those who are not too constrained by their physical conditions and may have a limited amount of surplus money, the second suggestion to achieve thermal comfort is by doing certain things around their house. These suggestions include guidelines on when to open or close the windows and blinds or curtains for achieving thermal comfort and minimise energy use, how to reduce or eliminate the cracks around windows and doors to reduce air leakage (in order to reduce heating), or how to minimise heat gain during hot days. For example by adding simple shade clothes or deciduous plants outside the windows. The next level up is a set of guidelines for older people who have some purchasing power (regardless of their physical conditions), and this includes making more significant changes to their house. For example, by adding insulation or even undertaking renovations, or installing (more) energy-efficient heating and cooling equipment. It should be noted, however, that providing tiered guidelines such as the above that are catered to the heterogeneity of older people including their financial and physical constraints does not eliminate the responsibilities of relevant agencies to provide financial support for them to achieve environmental sustainability. Nonetheless, such guidelines can help older people to take immediate actions without having to wait for financial help that may not come immediately.

2.8. *"Question 8: What are the effects of climate change and how does it interact with environmental sustainability for older people?"*

Answer: As outlined in detail by Dikken et al. [18], a new scientific discipline has emerged on the relationship between population ageing, environmental sustainability, and climate change awareness, as well as emergency preparedness and socio-environmental vulnerabilities of older people. The answer to Question 8 cannot be given without first touching upon the case of the '*climate grannies*'. In 2024, there was a ruling by the European Court of Human Rights in the case *Verein KlimaSeniorinnen Schweiz and Others* versus *Switzerland*, which made international headlines. The court ruled that mitigation of the negative effects of climate change is a matter of human rights [122]. The applicants in this case focused on health problems of older women that are exacerbated during heatwaves. The case was a prime exemplar of the current discourse in ageing and climate change. This discourse focuses on climate change mitigation through a better quality of buildings and the built environment (which is the topic of other questions in this study), as well as the adaptation to a changing climate and protection from temperature extremes.

Climate change causes more frequent extreme weather conditions which may affect older people. Heatwaves and hot weather [123–126], floods [127,128] or severely cold weather [104,129,130]) can have a serious impact on the quality of life, well-being, and health of older people and in some cases result in excess deaths [131,132]. Compared with younger people, older people are more susceptible to the negative effects of the changing climate. This is partially attributed to preexisting medical conditions, functional or cognitive impairments, which make them physiologically more susceptible to heat waves or air pollution for instance [133–135]. Physical constraints also make older people more susceptible during evacuation. For instance, older nursing home residents are found to have a higher mortality risk following evacuation [136]. Likewise, older people who live in poor and socially isolated environments are more likely to be at risk [137]. Hence, it is age in intersection with other attributes that make older people particularly susceptible to the changing climate [138]. Moreover, this greater susceptibility emphasises the role that social, political and economic institutions play in ensuring adequate adaptation and mitigation efforts among older people, given their physiological susceptibilities. Hence, climate change poses a substantial risk to older people's human rights as it directly impacts people's ability to access food, water, and adequate shelter. Another perspective is provided by Ulitsa and Ayalon [139], who studied the impact of climate and environmental changes on the experiences of 28 older immigrants migrating from the former Soviet Union to Israel during the 1990s. Their study shows the complexities concerning climate transition experiences, which go beyond those of the tradition scope of the climate change discourse.

This, however, is one side of the equation which receives most of the scientific attention and media exposure. As Lomborg [140] rightfully stated in 2020, climate change is real and its impacts are mostly negative, but common alarmist portrayals of devastation are unfounded, in particular when addressing the global death risk from extreme weather. Apart from hotter summers, there is the case of warmer winters. As we have seen in Question 6, in cold countries, older people may -in particular- experience the effects of rising energy prices in winter when heating is required to live in a comfortable dwelling. When looking at temperature-related mortality, we see that across the globe more older people die of cold weather events than of periods of excessive heat. This is in line with multi-country studies by Masselot et al. [141] and Zhao et al. [142], which show that more people die of cold than of heat. This ratio is 10 to 1 in temperature climate zones such as in North America and Europe, and still 9 to 1 across all continents. Similar ratios related to older people need to be established.

2.9. *"Question 9: What is the role of technology in the built environment in stimulating sustainability among older people?"*

Answer: The stimulation and support of sustainable lifestyles among older people cannot be discussed without the consideration of technological solutions. In recent years, smart home automation has grown, and various companies provide consumers with a range of products which can be integrated into their home depending on the needs and desires of the user [143]. In this section, we will discuss three different examples of new technologies which can stimulate sustainability among older people.

One such solution is the Internet of Things (IoT), which is not a new phenomenon although not every home or new housing estate is equipped with such technologies. IoTs can facilitate older people to monitor and control their heating/temperature [144], lighting, doorbell, washing machines [145], coffee machines, motion within the home, gas sensors (for instance, to detect carbon monoxide) and even smoke detectors [146]. IoTs are accessible via smartphone apps or in an analogue fashion, enabling older people with the digital skills [5,161] the opportunity to (remotely) monitor their home device. The IoT benefits for older people can facilitate them to control a specific occupied room (or zone), connected and controlled via voice assistants (such as Alexa and Google) in the house and can be scheduled for specific heating or cooling, accessible via multiple modes (smart device application, web browser or touch buttons) thus reducing electricity use [148].

Yet, the financial implication placed on older people of IoT installation is omitted from much of the information. The price range varies, and although IoT companies offer bundles for a combination of sensors or lights, they are more expensive than LEDs. Additional devices such as sensors, cameras, the control and monitoring system via a smartphone's app is an extra financial outlay. If an older person wishes to install a ring door camera, or an alarm system, it is likely that an electrician will be required to ensure everything is connected safely and efficiently, and this too is an additional financial outlay. Finally, additional costs can be incurred when someone is moving into another home which has an existing IoT system. Currently, there is still no option to transfer an existing IoT system over to the new homeowner because it requires a new registration of the IoT system to be connected to the person who purchased it. A new owner (or a tenant) would still be able to manually use and control the existing IoT system, they would not be able to access the information via the app. Thus, it is likely that the new owner may have to purchase a new system. These additional costs can prohibit (older) people with limited household incomes from adopting these new technologies.

Monitoring and remote controlling of heating, temperature, and lighting can be beneficial for older people using IoTs when they are away from home. For example, they can control the lighting in the house using their smartphone that has been connected to their indoor and outdoor lighting system. They can also turn on the outdoor light upon returning during home the winter months or control the heating and temperature in their home. Several companies such as Hive [149], Ring [150] - owned by Amazon (2024), or Philips Hue [151] offer older people the opportunity to transform their home into a 'smart home' based on the various products available. Overall, smart sensors can provide greater security to older people, encouraging them to be actively engaged in society without worrying about their house when they are away, while at the same time helping them use less energy for heating, cooling, lighting and other appliances at home. However, there are issues surrounding adoption, interpretation of data and engagement (user experience) of IoTs [152], compatibility, perceived usefulness, ease of use and visibility [153]. Further, the notion of perceived ease of use although significant according to the study conducted by Lu [153], is small regarding influence and adopting IoTs, aligning to findings from other studies [154–156]. Yet, the intention to use IoTs is perceived and valued highly, together with the benefits of well-being [153,156–159]. Moreover, in-home monitoring of IoTs is generally via a smartphone and for those people who do not own such a device, installing IoTs will force them to purchase a smartphone (additional expenses), if they wish to remote monitor. However, there is little known literature pertaining to the adoption of IoTs according to Kumar et al. [160]. Yet, Kumar and colleagues suggest future work should investigate the IoT ecosystem, trust, legal and regulation frameworks, in addition to the relationships and connections of artificial intelligence, Blockchain, cloud computing and digital twins [160]. With this in mind, drawing on areas relating to the digital divide, digital literacy [147,162], equity [5] through the lens of technology adoption and use could provide fruitful for inter-and-multidisciplinary research to understand further the adoption of IoTs and the exact beneficial use, challenges and concerns, employing a mixed methods approach to provide in-depth understanding in this arena. Morgan, and colleagues [163] identified communication and information were key issues surrounding technology and IoT adoption because of being digitally excluded. Likewise, understanding how communities in the Global South [164–167], low-income households and vulnerable people would use IoTs - building on the work of Tirado Herrero et al. [168] - would afford researchers and policymakers to understand how IoTs can be fully equitable in a society that only the haves may benefit from.

In the UK the use and implementation of solar panels is a relatively

new mode of technology in the home domain (since 2011), with solar farms commencing in 2007 [169]. Historically, the installation of solar panels on residential homes was paid for by the individual(s), following a new business model whereby the roof of a home would be 'rented' out to 'host' the panels [169]. This approach led to many homes receiving discounted electricity, but with new reduced tariffs this scheme of 'rent a roof' was perceived as less attractive because of the UK Government's 'Feed-in-Tariff' (FiT) which ceased in 2019, and has resulted in higher installation costs [170]. In Australia, solar panels have gained 'popularity' since 2010. The recent statistics show that more than 35% of homes in Australia have had solar panels installed on their roof [171]. This proportion is also reflected in a recent study of homes of low socio-economic older people in South Australia [82]. In the Netherlands, Boerenfijn et al. [172] describe the lease contracts for installation solar panels on top of nursing homes and other housing facilities for older people by third parties.

Although, heat pumps, either ground source, air source or water source [173], are considered to be more efficient way of heating homes, in the context of residential buildings they are a relatively new phenomenon in many countries. For example, between 2009 and 2010 in the UK, 200,000 heat pumps were sold and nearly half were installed into retrofitted properties while in 2007 there were less than 2000 ground source heat pumps sold (but no data was available for air source) [174]. In the UK, the estimated costs for (heat/water) pump installations range between £10–14k, and for some (older) people they may be able to receive a government installation grant of £7500.00 [173,176] until 2028, aiding homeowners (including older people) to upgrade their gas boilers with a heat pump, aligned to the UK government meeting its Net Zero strategy [175].

2.10. *"Question 10: What more can be done for and by older people to live in an environmentally sustainable built environment?"*

Answer: The ongoing ageing of the population can have both positive and negative outcomes on sustainable development. Wang et al. [177] found that ageing can reduce the environmental pressures related to urbanisation, in particular, when higher and upper middle incomes of older people are involved in the improvement of environmental quality. In this case, the financial factor comes to the fore as being a driver of sustainable development, as was the case with age-friendliness [178]. Qian et al. [179] and Han et al. [180] studied the nexus between age-friendly and sustainability through surveying older people and by focussing on this group as active contributors to sustainable urban development. Again, the link between the two fields of action was stressed as an important way of moving our societies forward. Cheval et al. [181] revealed that age plays an important role in accepting the urgency of policies associated with sustainability and environmental protection. Again, attitudes correlate with economic and financial issues. This is also the case for investing in renewable energy sources where financial constraints on older people hamper such investments [182]. At the same time, in countries where older people are more likely to be homeowners, they are also the group that benefits most. Other studies have shown similar outcomes: the more affluent older people are, the more inclined they are to invest in renewable energy sources, and vice versa [68,183]. Pais-Magalhães et al. [68] further stressed the rising number of single older households and the impact on overall energy consumption. Conversely, there are some older adults who face the problem of economic burdens when it comes to such investments. Many of the green transition solutions are designed as investments that will break-even typically after a period of at least 10 years [184], and such economic challenges are only one of four main areas which also include challenges in terms of health and well-being, social and community challenges, as well as policy and regulatory challenges. In the case of older people such a long return on investment makes these proposals highly unappealing. Fortunately, there are some pilot projects of more attractive financial schemes, like the case of a local photovoltaic panel installation programme introduced in Australia [185]. Positive actions are not just limited to living in the community. Older people residing in nursing homes can still contribute to the improvement of the sustainability of their facility in engaging and meaningful ways, as was shown in cases described by Boerenfijn et al. [172], which included so-called energy battles and the installation of sustainable and renewable energy systems in the homes for older people. Other researchers [107,186,187] have focused on the energy habits and energy consumption patterns of older people, and identified ways sustainable development goals can be met by older people. This short overview shows that older people, providing that they have access to financial means and sufficient support and information, can be important actors in making the built environment more sustainable as shown by van Hoof and Dikken [31] and Dikken et al. [18]. This means that governments wishing to involve older people in achieving sustainability goals have to focus on these three elements (financial aspects, beliefs and pro-environmental behaviours). A study by PBL Netherlands Environmental Assessment Agency [188] concluded that many older people have an investment horizon of less than 20 years, and, therefore, one should ask whether policies should steer towards the implementation of sustainable solutions at home. Too much coercion that should lead to the desired investments from a societal point of view, even when such investments conflict with personal interests, are not considered a desirable direction. In this view, we need more carrots and fewer sticks. Schilder [188] also raises the issue of self-management in relation to insulating one's own home or generating renewable energy at home, which depends on one's personal capacities, financial position, information skills and available resources.

An important aspect of a successful implementation of more complex and technically advanced green solutions could be to close the involvement of intermediaries that will bridge the gap in knowhow and help understand how to apply these technologies in a user-friendly way for older adults to understand much better [189]. These intermediaries could also be their peers, who have previously learnt and implemented these solutions successfully and who are happy to demonstrate and pass on their knowledge to others [190]. The fact that they are in the same age group would increase their credibility in the eyes of potential new users. Identifying these people who could serve as mentors is a crucial piece in the overall action plan to make the built environment sustainable, as they are key nodes in the social network. Potentially, society can achieve an effect by training only a few local ambassadors who can have an impact on many.

How to move forward? In 2011, Pillemer et al. [191] posited a research agenda for environmental sustainability in an ageing society. In over a decade's time, these topics have stood the test of time and are still relevant particularly in terms of intersectionality with economic diversity, geographical region, and intergenerational linkages, which have also appeared in the nine questions outlined above. Relating to the variety of fitting solutions for the geographical regions older people live in, Dikken et al. [18] have stressed the need for cross-cultural studies, spanning a larger group of countries, and preferably climatic zones. Given the fact that the SDGs and their connection to ageing societies [22] have a global applicability, it would be of scientific and societal interest to see which solutions work in multiple countries and which solutions have a cultural dimension that restrict their application to only particular countries or cultures. More evidence gaps that lend themselves for future research have been provided by Hu [15] who stressed the interdisciplinary challenges connected to the sustainability agenda for older people and the need for cross-cultural or multi-centre research. An interesting route to explore would be to enhance a citizen science approach, which drives community empowerment by promoting participation, creating vital knowledge, and engaging citizens in actions towards sustainability [192]. Involving older people at different levels of citizen science, including contributory, collaborative, co-creation or citizen-led tier [193], may be perceived as a longer and more time-consuming solution. However, considering the resources necessary

to overcome future barriers to implementation, it may be a more effective strategy. Awareness that older people are not only receivers but also co-creators of solutions may increase their willingness to accept and adopt them in the future.

3. Conclusions and recommendations

In the following sections we provide an overview of the main findings, recommendations for policy, recommendations for future research, and implications for practice and older people themselves.

3.1. Main findings

This paper examines the intricate relationship between older adults and environmental sustainability in the built environment, addressing ten key questions. The findings reveal that older adults generally hold positive attitudes towards sustainability (Q1), shaped by personal values, past experiences, and a belief in the efficacy of their actions. While generational differences in sustainable practices exist between younger and older cohorts (Q2), behaviours are highly context-dependent, cautioning against broad generalisations. The lack of a large set of standardised, age-sensitive tools complicates the quantitative, qualitative and mixed-method assessment and comparison of sustainable behaviours across demographics, highlighting a critical gap in current methodologies (Q3). Older adults face unique barriers to adopting sustainable practices, including physical limitations, financial constraints, and cognitive challenges (Q4). Despite these obstacles, sustainability offers significant opportunities to enhance their health, well-being, and social connectedness as well as one's financial position (Q5). Rising energy costs pose a particular threat to vulnerable older adults, emphasising the need for targeted support to address energy poverty among to those who can no longer afford their utility bills (Q6). Effective sustainable living requires a holistic approach that integrates individual efforts with community initiatives and supportive policies (Q7). Furthermore, older adults are especially vulnerable to the impact of heat waves, underscoring the necessity of tailored adaptation strategies that they can also implement themselves in the broader light of climate change mitigation (Q8). Emerging and existing technologies present opportunities to support sustainable lifestyles, but their potential is contingent on affordability, accessibility and even digital literacy (Q9). Overall, the findings emphasise the importance of recognising the diversity among older adults and designing interventions that meet their specific needs (Q10).

3.2. Policy recommendations

To promote sustainability among older adults, targeted (educational) campaigns from public bodies are essential to address their specific motivations and concerns regarding environmental sustainability (Q1). These campaigns can foster a deeper understanding of sustainable practices and encourage meaningful engagement. Intergenerational collaboration should also be prioritised, as it facilitates knowledge exchange and mutual learning between different age groups, fostering a shared responsibility for sustainability (Q2). Developing standardised, age-sensitive tools is crucial to assess and monitor sustainable behaviours across demographics in order to inform policies concerning older people and sustainability (Q3). Policies must focus on removing barriers that hinder older adults' participation in sustainable practices, such as physical limitations and financial constraints (Q4). Integrating sustainability into health and social care policies can amplify its benefits by promoting active ageing and enhancing overall well-being in all of its facets (Q5). Addressing energy poverty requires targeted interventions to alleviate the financial burden of rising energy costs on low-income older adults, part of which is caused by government taxation particularly in high-income countries (Q6). Community-based initiatives play a vital role in empowering older adults to actively contribute to the creation of sustainable environments and lead a sustainable lifestyle (Q7). Climate resilience strategies must specifically address the vulnerabilities of older adults to protect their well-being while recognising their potential to contribute to 'climate action' (Q8). Finally, promoting and ensuring accessibility to, and affordability of, sustainable technologies can enable older adults to leverage technological advancements for sustainable living, as long as these technologies meet the challenges of older people struggling with digital literacy and limited access to information (Q9). These measures, underpinned by robust research, can inform evidence-based policymaking and help create age-friendly and sustainable communities for present and future (older) generations (Q10).

3.3. Recommendations for future research

Future research should explore the diverse motivations and barriers influencing older adults' adoption of sustainable practices (Q1). Comparative studies across age cohorts are needed to investigate specific behaviours and contextual factors, avoiding overly broad generalisations (Q2). The development of standardised, age-sensitive assessment tools will improve the measurement and monitoring of sustainable practices and allow for multi-country comparisons (Q3). Research should further examine the unique challenges older adults face, such as physical and cognitive limitations as well as financial constraints, to ensure that interventions are both effective and equitable (Q4). Studies exploring the multifaceted benefits of sustainable practices for older adults—such as improvements in physical, mental, financial and social well-being—can highlight the value of sustainability (Q5). Additionally, targeted research on interventions to address energy poverty among older adults is vital to ensure equitable access to resources, also in the light of further environmental and sustainable policies developed by governments and supranational organisations (Q6). Qualitative studies on the lived experiences of older adults engaged in sustainable lifestyles can provide insights into their motivations and challenges (Q7). A nuanced understanding of their specific vulnerabilities to climate change impacts (as well as the benefits of enjoying milder winters) and evaluating the efficacy of personal and (supra)national adaptation strategies are critical areas for future research (Q8). Investigating the accessibility and usability of new technologies for older adults, with a focus on affordability and digital literacy, is equally important (Q9). Lastly, transdisciplinary research integrating perspectives from gerontology, urban planning, environmental science, and technology will enable a holistic understanding of ageing, sustainability, and the built environment (Q10).

3.4. Implications for practice

Sustainability initiatives should prioritise the needs of older adults by tailoring solutions to their specific circumstances (Q1). Educational campaigns that resonate with older people's values and experiences can encourage greater engagement with sustainable practices. Intergenerational partnerships are particularly effective, fostering knowledge exchange and collaboration between older and younger generations (Q2). Age-sensitive design principles should guide the development of sustainable solutions, ensuring accessibility and relevance for older adults (Q3, Q4). Integrating sustainability into health, income, housing and social care programmes can simultaneously enhance environmental outcomes and improve older adults' quality of life (Q5). To address energy poverty, targeted assistance programmes should be refined and/or developed, offering support to those most affected by rising energy costs and the potential effects of poor quality of housing (Q6). Creating age-friendly community spaces that promote sustainable lifestyles empowers older adults to take an active role in environmental initiatives (Q7). Climate resilience plans must consider the unique vulnerabilities of older adults, providing tailored solutions to protect their well-being and stress the potential of older people to help mitigate climate

change instead of being passive observers (Q8). Additionally, promoting access to and affordability of technologies will help older adults leverage technological advancements for sustainable living (Q9). Collaboration among policymakers, practitioners, and older adults is crucial to developing sustainable communities (Q10).

3.5. Implications for older adults

Older adults have a critical role to play in promoting sustainability, although the heterogeneity of this group should once again be stressed. Recognising the value of their diverse experiences and contributions can empower older people to actively participate in sustainability initiatives (Q1). Engaging in intergenerational dialogues fosters mutual understanding and shared responsibility for environmental stewardship, instead of nurturing a polarising discourse that is more divisive and stressing an assumed role of older people in the current state of affairs concerning the depletion of natural resources (Q2). By utilising available resources and support systems, older adults can overcome barriers and adopt sustainable practices that enhance their well-being and social connections (Q3, Q4, Q5). Advocating for policies addressing energy affordability (for all) and better quality of housing ensures equitable access to essential resources (Q6), while participating in community-based initiatives creates opportunities for social engagement and collective action (Q7). Preparing for climate change impacts, such as developing emergency response plans and the installation of frugal solutions in the home environment, can enhance resilience and protect the health of older people – in the full realisation that such preparations go together with financial investments that may not be paid back during the older person's lifespan (Q8). Exploring and adopting affordable technologies that support sustainable living further empowers older adults to contribute to environmental sustainability (Q9). Sharing their knowledge and experiences with younger generations can inspire others and help build a more sustainable future for all (Q10).

CRediT authorship contribution statement

J. van Hoof: Writing – review & editing, Writing – original draft, Supervision, Project administration, Investigation, Funding acquisition, Formal analysis, Conceptualization. **V. Soebarto:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Conceptualization. **L. Ayalon:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **H.R. Marston:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **K.K. Zander:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis. **J. Dikken:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Formal analysis. **J.K. Kazak:** Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgements

This publication is based upon work from the project City&Co: Older Adults Co-Creating a Sustainable Age-friendly City (JPI project number 99950200). This project was funded by the Taskforce for Applied Research (UTC.01.1), National Science Centre (UMO-2021/03/Y/HS6/00213), and Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI) (Contract nr: 298 / 2022), as part of ERA-NET Cofund Urban Transformation Capacities (ENUTC), co-funded by the European Union's Horizon 2020 research and innovation programme under grant agreement no. 101003758.

Data availability

No data was used for the research described in the article.

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Joost van Hoof is a full professor of Urban Ageing with The Hague University of Applied Sciences in The Netherlands. He has a background in building physics and services, and holds both a DSc and a PhD degree in the design of housing facilities for older people (with dementia). He is also affiliated with the Wrocław University of Environmental and Life Sciences in Poland.

Veronica Soebarto is a Professor in the School of Architecture and Civil Engineering, The University of Adelaide. Her background is architecture and architectural science. She conducts research relating to older people and the built environment, both in relation to housing and green spaces, and how the built environment impacts the well-being of older people.

Liat Ayalon is a Professor in the School of Social Work, at Bar Ilan University, Israel. Prof. Ayalon was the coordinator of an international EU funded Ph.D. programme on the topic of ageism (EuroAgeism.eu; 2017–2022). Between 2014 and 2018, Prof. Ayalon has led an international research network on the topic of ageism, funded through COST (Cooperation in Science and Technology; COST IS1402, notoageism.com). She consults both national and international organisations concerning the development and evaluation of programmes and services for older adults. In recognition of her work, Prof. Ayalon was selected by the UN Decade of Healthy Ageing as one of 50 world leaders working to transform the world to be a better place in which to grow older.

Hannah R. Marston is a research fellow at the Health and Wellbeing Strategic Research Area (H&W SRA) at the Open University in the United Kingdom. She has a background in computing and holds a PhD in virtual reality and gerontology. She has published widely on the benefits of technology for older adults living in urban and remote communities.

Kerstin K. Zander is a Professor at the Northern Institute at Charles Darwin University in Australia. She holds a PhD in Environmental and Resource Economics from the University of Bonn in Germany. Her research is looking at the diverse relationships between humans and nature and aspires to increasing human well-being and sustainability while helping people cope with changing environments and natural hazards.

Jeroen Dikken is an associate professor with the Research Group of Urban Ageing and a principal lecturer of nursing with The Hague University of Applied Sciences in The Netherlands. He is a Registered Nurse (RN), holds a Master degree in both Health Sciences as well as Gerontology, and has a doctoral degree in Nursing Sciences.

Jan K. Kazak is an associate professor at the Wrocław University of Environmental and Life Sciences and the head of Leading Research Group "Sustainable Cities and Regions". He has a background in sustainable solutions for spatial management and adaptation to climate change, and holds a PhD degree in environmental studies and a DSc degree in engineering and technical sciences.