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Indoor Built Environment and Older Adults' Activity: A Systematic Review

Farah T. Azim[1], Patrocinio Ariza-Vega[2], Paul A. Gardiner[3] and Maureen C. Ashe[1]

[1]Department of Family Practice, The University of British Columbia, Vancouver, British Columbia, Canada, [2]Faculty of Health Sciences, University of Granada, ibs.Granada, Granada, Spain and [3]School of Health and Medical Sciences, University of Southern Queensland, Ipswich, Queensland, Australia

Article

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Corresponding author:
La correspondance et les demandes de tirés-à-part doivent être adressées à : / Correspondence and requests for offprints should be sent to: Maureen C. Ashe, Ph.D., Department of Family Practice, 7F – 2635 Laurel Street, Vancouver, BC, Canada, V5Z 1M9 (maureen.ashe@ubc.ca)

Résumé

Bien que l'environnement physique puisse influencer l'activité des individus, peu de synthèses de connaissances portent sur les environnements intérieurs et les routines de la vie quotidienne des personnes âgées. Nous avons donc procédé à un examen systématique de publications revues par des pairs afin de guider les recherches et les pratiques futures. Les critères d'inclusion suivants ont été utilisés : études sans restriction quant au devis de recherche, à la date ou à la langue, portant sur les personnes âgées de 60 ans et plus, sur l'activité physique ou le comportement sédentaire, et l'environnement intérieur. Après avoir effectué des recherches dans cinq bases de données, deux des auteurs ont examiné les titres, les résumés et le texte intégral. La dernière recherche a été effectuée le 19 décembre 2020. Nous avons passé en revue 1367 citations et inclus 23 études se rapportant à des logements privés ou collectifs (p. ex. résidences avec services). Les caractéristiques intérieures favorisant l'activité physique étaient associées à trois domaines : les environs (p. ex. les commodités, les chemins), le bâtiment (p. ex. la superficie, le niveau de l'étage) et les équipements (p. ex. les ascenseurs, les couloirs). La connaissance des facteurs environnementaux intérieurs qui favorisent la participation des personnes âgées aux activités quotidiennes peut orienter les recherches et les politiques futures en matière de conception de logements.

Abstract

Although the physical environment can influence people's activity, there are few knowledge syntheses for indoor environments and older adults' daily life routines. Therefore, we conducted a systematic review of peer-reviewed evidence to inform future research and practice. Inclusion criteria were studies with any research designs, across all years and languages focused on older adults 60 years of age or more, on physical activity/sedentary behaviour and the indoor environment. After searching five databases, two authors completed title/abstract and full-text screening. The last search was on December 19, 2020. We screened 1,367 citations, and included 23 studies situated in private or collective dwellings (e.g., assisted living). We identified physical activity-supportive indoor features across three domains: campus (e.g., amenities, pathways), building (e.g., area, floor level), and fixtures (e.g., elevators, hallways). Knowledge of indoor environmental factors for older adults' engagement in daily activities can guide future research and policy on housing design.

Most people spend the majority of each day indoors (Klepeis et al., 2001), and this time most likely increased with the COVID-19 pandemic. Pandemic-related lockdowns decreased many people's engagement in physical activity – possibly up to 30 per cent – with a simultaneous increase in sedentary behaviour (Ammar et al., 2020) as a result of the changes in their daily routines. Older adults may be particularly susceptible to reduced physical activity resulting from restricted community mobility and activities limited in aged care facilities. Being active at home may be an important opportunity to mitigate the negative consequences of reduced life space. Therefore now, and beyond the current pandemic, it is important to identify features of the indoor built environment to promote physical activity in general, and specifically for older adults who may have mobility impairments.

In 2020, older adults 60 years of age and older comprised 13 per cent of the global population (World Health Organization, 2020a). In Canada in 2018, there were more older Canadians (17%) (Organisation for Economic Co-operation and Development, 2021a) than Canadian children and youth under 15 years (16%) (Organisation for Economic Co-operation and Development, 2021b). As the population of older adults in Canada grows, policies and practice must enable healthy aging in place. Aging in place is about honoring connections to the social and physical environments that shape people as they grow older (World Health Organization, 2020a). Along

with housing, aging in place is also facilitated by how older adults care for themselves through engagement in physical activity (Tao, Zhang, Gou, Jiang, & Qi, 2021; Van Holle et al., 2016; Yen, Michael, & Perdue, 2009). Furthermore, older adults often participate in physical activity at home, rather than in other locations (Chaudhury, Campo, Michael, & Mahmood, 2016). Physical activity can improve physical function, and reduce the risk of chronic diseases and adverse events, such as falls (World Health Organization, 2020b). In contrast, prolonged sedentary behaviour can increase the risk of chronic conditions (e.g., type-2 diabetes) and lead to poor health outcomes (World Health Organization, 2020b).

There are systematic reviews on the effect of the built environment on physical activity for various demographics, focusing on neighborhood, active transport, and outdoor environment design (Smith et al., 2017; Tcymbal et al., 2020; Thornton et al., 2017; Yen et al., 2009). Studies have frequently explored the effect of the built environment on older adults and their physical activity (Cerin, Nathan, van Cauwenberg, Barnett, & Barnett, 2017; Tao et al., 2021; Van Holle et al., 2014, 2016). Despite the increasing evidence base for the outdoor environment, less emphasis has been placed on the indoor physical features needed to support active living for older adults (Ahrentzen & Tural, 2015; Annear et al., 2014; Ashe, 2018) even though most people spend most of the day inside.

Therefore, the aim of this systematic review was to synthesize available evidence across all study designs to describe features of the indoor environment and physical activity and/or sedentary behaviour for older adults 60 years of age and older. For this synthesis, we define the indoor built environment as internal space(s) in which older adults reside and engage, and adjacent spaces (e.g., backyard, porch, driveway) (Peel et al., 2005).

Methods

We used the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines to conduct this systematic review (Moher, Liberati, Tetzlaff, & Altman, 2009), and registered it with PROSPERO (Registration No. CRD42018095359).

Inclusion and Exclusion Criteria

We included studies using any study designs, years, and languages. The study population included older adults 60 years of age and older, or the mean age of the study sample was over 60 years of age. Studies included outcomes related to physical activity and/or sedentary behaviour of older adults. The studies also reported features of the indoor environment. We excluded studies if they focused on populations younger than 60 years, or on people with dementia and falls-related research. A "one size fits all" approach does not apply to all individuals in a population, and this is especially true for people with dementia or falls-related research. We also excluded studies focused on ambient indoor temperature, because it is not part of the built environment. We excluded studies without physical activity or sedentary behaviour outcomes.

Information Sources and Search Strategy

We searched the following databases: MEDLINE® and Embase, EBSCO Databases, PubMed, and Google Scholar (title only). We used the following headings to guide our search: population (older adults), exposure (indoor environment), outcome (physical activity or sedentary behaviour). The search strategy for MEDLINE is provided in Table 1. We conducted forward and backward citation searches for included studies. We completed our last search on December 19, 2020.

Study Selection

Two authors (FA, MA) completed title and abstract screening (Level 1) based on a priori criteria. For Level 2 screening, the full texts of all included studies were reviewed by the same two authors (Figure 1); they resolved discrepancies through discussion and consensus.

Data Extraction

We extracted the following information for each study: title, first author, year, location, conflicts of interest, purpose, study design, funding resources, participants, indoor and/or housing and campus features, and physical activity and sedentary behaviour outcomes. One author extracted data (F.A.), and a second author (M.A.) checked 10 per cent of entries for accuracy. The same two authors (F.A., M.A.) checked the data again during the synthesis process. We used Covidence by Veritas Health Innovation (Melbourne, Australia) to conduct this review.

Physical Activity and Sedentary Behaviour

Physical activity is energy expenditure produced by skeletal muscles during movement (Caspersen, Powell, & Christenson, 1985; World Health Organization, 2020b) and it includes various household activities (e.g., activities of daily living [ADLs]), sports,exercise (defined as planned and repetitive movement; e.g., swimming), and other activities (e.g., work-related) (Caspersen et al., 1985). Sedentary behaviour is defined as "any waking behaviour characterized by an energy expenditure ≤1.5 metabolic equivalents of task (METs), while in a sitting, reclining, or lying posture" (Sedentary Behaviour Research Network, 2012, p. 1). In our synthesis, we use the terms physical activity or sedentary behaviour (as defined here), or specify the type of physical activity (e.g., ADLs, exercise, walking).

Table 1. MEDLINE search strategy

Search Terms
1. (sitting or sedentary behavior or sedentary behaviour or physical activity or exercise or fitness or physical exercise or sport).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
2. (older adults or elderly or seniors or geriatrics or aging or age-related).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
3. (housing or indoor).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
4. 1 and 2 and 3

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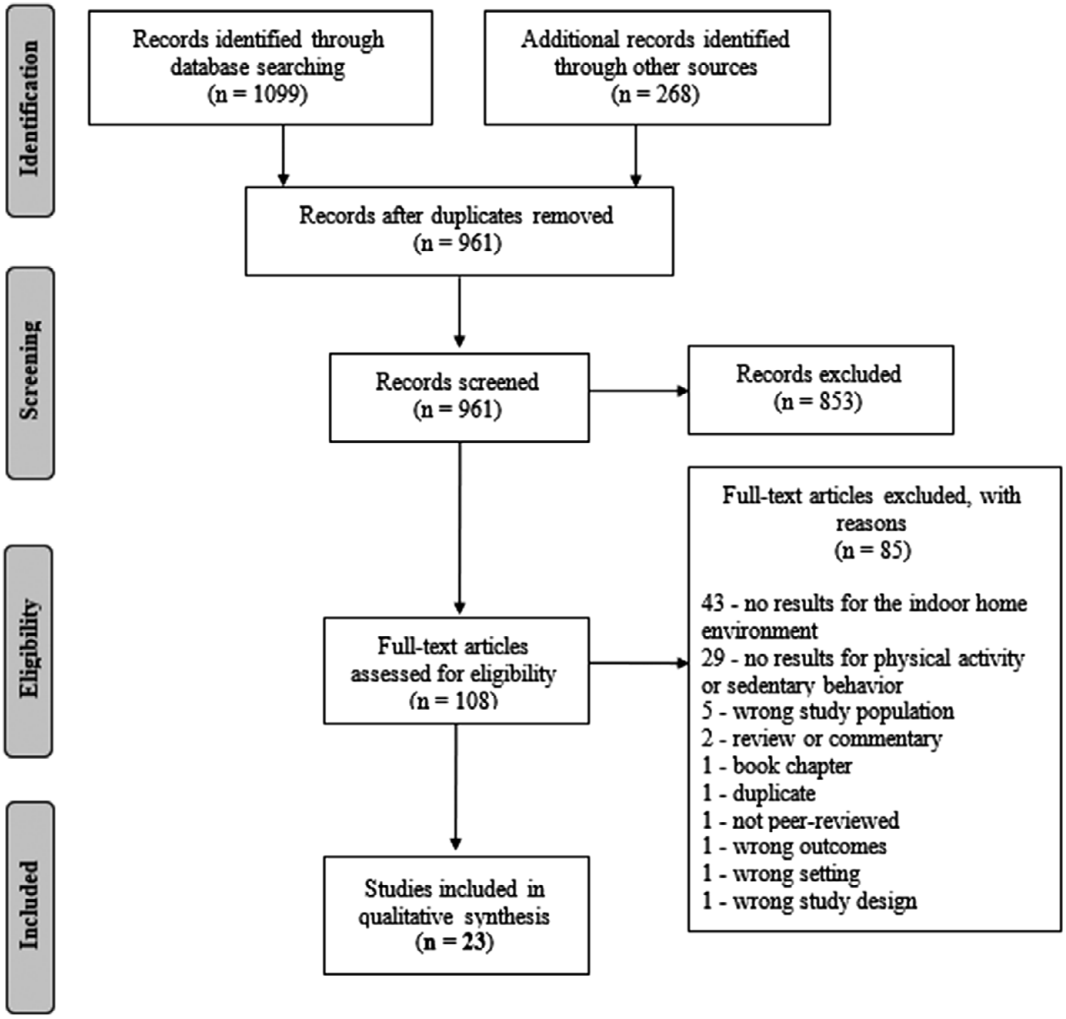

Figure 1. PRISMA flow diagram

Private and Collective Dwellings

We defined private dwellings (e.g., houses, apartments, town homes) as residences where older adults resided in their own or rented property with access to a private entrance (Statistics Canada, 2017b) and in a community of their choice (U.S. Department of Health and Human Services, n.d.). Collective dwellings (e.g., independent living, assisted living, and retirement villages) are residences where older adults either have private or shared units, live amongst a collective of older adults, and receive a range of services from meal preparation to bathing, as required (BC Seniors Living Association, 2021; Province of British Columbia, 2021; Statistics Canada, 2017a). We define "campus" as the site or property of collective dwellings and campus features, including available resources (e.g., pools, gyms) and destinations (e.g., clubhouses, gardens, and shops).

Indoor Environments

We extracted data on features of the indoor and adjacent environments. The indoor environment was within the residential unit, whereas features of the adjacent spaces were immediately outside the residential unit (Peel et al., 2005). In private dwellings, residential units included the house or apartment, and adjacent spaces included indoor hallways in apartments, backyards, gardens, and front lawns (e.g., distance between the house and garbage disposal or mailbox) (Peel et al., 2005). For collective dwellings, there were living units, resources (e.g., indoor, and outdoor pools), destinations (e.g., clubhouses, shops) and other features (e.g., indoor hallways and outdoor paths) located on the campus.

Quality Assessment

Two authors (FA-MA) evaluated the selected studies using the Standard Quality Assessment Criteria for Evaluating Primary Research Papers or the *"QualSyst"* tool (Kmet, Lee, & Cook, 2004), and discrepancies in scores were resolved through consensus. We did not exclude studies that were of low quality.

Synthesis of Results

Two authors (FA, MA) used qualitative synthesis methods via an inductive content analysis (Mikkonen & Kääriäinen, 2020) over three 1-hour sessions. After checking extracted data, indoor environment features were presented on a digital whiteboard. The two authors first independently created themes from the data, then discussed themes. Between the two meetings, each author checked

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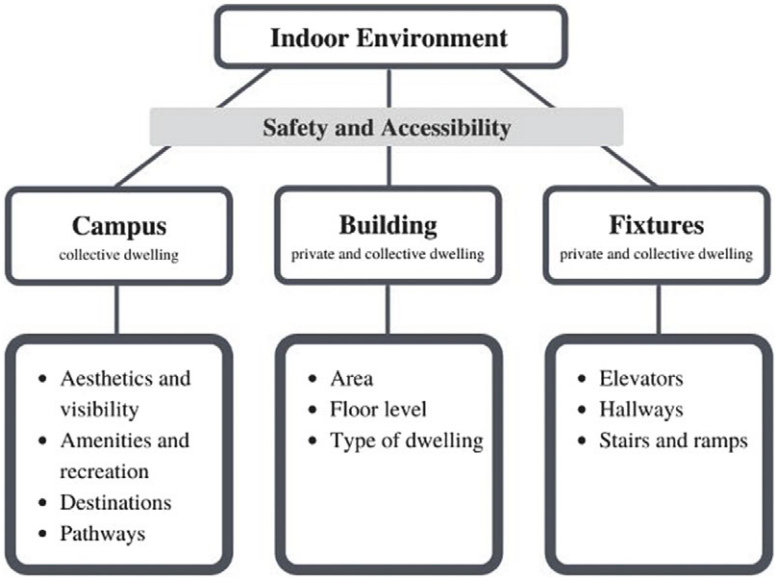

Figure 2. Visual summary of the findings from the included studies. The findings represent two settings (collective and private dwellings) and three domains (campus, building, and fixtures). Campus features were only identified in the collective dwelling setting. Accessibility and safety domains are important across settings.

the coded data and noted any discrepancies or questions to discuss at the next meeting. During the final meeting, authors confirmed the findings and created a visual representation of the synthesis (Figure 2). We present the mean and standard deviations, if available, in the tables. If this information was not available, we included other data (e.g., median, interquartile range).

Results

Study Characteristics and Quality

Our search strategy resulted in 1367 studies of which 23 studies were included (see Figure 1 for the PRISMA Flow Diagram) (Moher et al., 2009). We included studies with different designs (e.g., observational, pre-post) and publication dates ranged from 1995 to 2020. Studies were from the following locations: Canada (6) (Haney, Fletcher, & Robertson-Wilson, 2018; Harrison et al., 2010; Patry et al., 2019; Regan et al., 2016; Reid, 2004; Voss, Pope, & Copeland, 2020); Sweden (4) (Lilja & Borell, 1997; Niva & Skär, 2006; Petersson, Lilja, & Borell, 2012; Thordardottir, Fange, Chiatti, & Ekstam, 2020); United States (4) (Cress, Orini, & Kinsler, 2011; Joseph & Zimring, 2007; Joseph, Zimring, Harris-Kojetin, & Kiefer, 2005; Kotlarczyk et al., 2020); Australia (3) (Aplin, de Jonge, & Gustafsson, 2015; Nathan, Wood, & Giles-Corti, 2014b; Pettigrew et al., 2020); Finland (1) (Portegijs, Rantakokko, Viljanen, Rantanen, & Iwarsson, 2017); Germany (1) (Benzinger et al., 2014); Korea (1) (Park, Park, Hancox, Castaneda-Gameros, & Koo, 2019); The Netherlands (1) (van den Hombergh, Schouten, van Staveren, van Amelsvoort, & Kok, 1995); Spain (1) (Perez-Hernandez et al., 2018); and Taiwan (1) (Cheng, Wang, Tang, Chu, & Chen, 2014). The included studies were from higher income countries (The World Bank Group, n.d.). Table 2 provides study summary information.

Table 3 reports the quality of included studies. For the Qualsyst tool, quality scores can range from 0.00 to 1.00. The only mixed methods study (Reid, 2004) included in this review received the lowest scores (0.45 for qualitative and 0.65 for quantitative criteria). The remaining studies received high quality scores ranged from 0.85 to 1.00.

Participants

The mean group age across studies was 60 years or older. Four studies included participants below 60 years of age (Aplin et al., 2015; Petersson et al., 2012; Reid, 2004; Thordardottir et al., 2020). Twelve studies reported on participants' mobility limitations (Aplin et al., 2015; Joseph & Zimring, 2007; Kotlarczyk et al., 2020; Lilja & Borell, 1997; Niva & Skär, 2006; Perez-Hernandez et al., 2018; Petersson et al., 2012; Portegijs et al., 2017; Reid, 2004; Thordardottir et al., 2020; van den Hombergh et al., 1995; Voss et al., 2020, and participants used assistive devices (e.g., walking aids and scooters) in four studies (Benzinger et al., 2014; Cheng et al., 2014; Nathan et al., 2014a,b; Park et al., 2019). Table 2 highlights that most studies had a study population with more women than men, but one study did not report gender (Joseph et al., 2005). Of the four studies which reported race (Cress et al., 2011; Kotlarczyk et al., 2020; Park et al., 2019; Reid, 2004), most participants self-reported as white. These studies were conducted in Canada (Reid, 2004), Korea (Park et al., 2019), and the United States (Cress et al., 2011; Kotlarczyk et al., 2020).

Housing

Ten studies observed participants in private dwellings (Aplin et al., 2015; Benzinger et al., 2014; Niva & Skär, 2006; Patry et al., 2019; Perez-Hernandez et al., 2018; Petersson et al., 2012; Portegijs et al., 2017; Reid, 2004; Thordardottir et al., 2020; van den Hombergh et al., 1995); six observed participants in collective dwellings (Cheng et al., 2014; Joseph et al., 2005; Joseph & Zimring, 2007; Kotlarczyk et al., 2020; Nathan et al., 2014a, 2014b; Voss et al., 2020); five studies compared between dwellings (Cress et al., 2011; Harrison et al., 2010; Lilja & Borell, 1997; Park et al., 2019; Pettigrew et al., 2020), while two studies observed older adults as they transitioned to a collective dwelling (Haney et al., 2018; Regan et al., 2016). The age range of

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Table 2. Study and participant information of included studies

First Author and Year, Country, Study Design	Type of Dwelling[a]	*n*, Age (years), Gender, Race	Mobility Instruments[b]	Mobility Status[b]
Aplin et al. (2015) Australia Qualitative descriptive study	Private	55 64, 25–87 (mean, range) 30 women, 25 men Race was not reported.	Study only included participants who required home adaptations.	
Benzinger et al. (2014) Germany Cross-sectional study	Private	81 79, 76–83 (median, IQR) 39 women, 42 men Race was not reported.	Housing enabler[c]	Number of self-reported functional limitations: 2, 1-4 (mean, IQR)
Cheng et al. (2014) Taiwan Cohort study	Collective	250 75.35 (8.65) 70 women, 180 men Race was not reported.	Use of mobility aid	42.8% use scooter 4.8% use wheelchair, walker, or crutch
Cress et al. (2011) USA Cross-sectional study	Private and collective	Private: 31 76.3 (7.6) 61.3% women 100% white Collective: 30 82.7 (5.5) 60.0% women 100% white	Medical Outcomes Short Form-12[d]	Physical function score • Private: 73.71 (23) • Collective: 64.17 (21)
Haney et al. (2018) Canada Qualitative study	Transition to collective dwelling	9 84.2 9 women Race was not reported.	Not reported	
Harrison et al. (2010) Canada Cross-sectional study	Private and collective	Private: 312 76.2 (8.4) 226 women, 86 men Collective: 397 78.7 (8.3) 338 women, 59 men Race was not reported.	Medical Outcomes Short Form–12[d]	Mean physical function score • Private: 60.1 (38.8) • Collective: 51.7 (36.1)
Joseph & Zimring (2007) USA Cross-sectional study	Collective (three locations)	Parkview: 38 78 (mean) 22 women, 16 men Lakeview: 40 77 (mean) 21 women, 19 men Greenacres: 36 83 (mean) 24 women, 12 men Race was not reported.	Use of mobility aid for walking	Mobility aid use (*n*) • Parkview: 3/38 • Lakeview: 3/40 • Greenacres: 9/36
Joseph et al. (2005) USA Questionnaire study	Collective	Independent living: 157 (mean population) 82 (mean) Assisted living: 45 (mean population) 85 (mean) Gender and race were not reported.		None
Kotlarczyk et al. (2020) USA Focus groups, semi-structured interviews	Collective	Independent living: 22 86, 65–93 (mean, range) 14 women, 8 men 100% white Assisted living: 22 86, 65–97 (mean, range) 17 women, 5 men 90.9% white	Use of mobility aid	72.7% use mobility aids

(Continued)

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Table 2. *Continued*

First Author and Year, Country, Study Design	Type of Dwelling[a]	*n*, Age (years), Gender, Race	Mobility Instruments[b]	Mobility Status[b]
Lilja & Borell (1997) Sweden Longitudinal study	Private and collective	Group A (used elevator with support): 284 84.5 (mean) 81% women, 19% men Group B (used elevator independently): 325 81 (mean) 75% women, 25% men Race was not reported.	Difficulties with mobility	91% of Group A had issues with mobility 65% of Group B had issues with mobility
Nathan et al. (2014a, b) Australia Cross-sectional study	Collective	323 76.9 (7.3) 220 women, 103 men Race was not reported.	Medical Outcomes Short Form–12[d]	Physical function score: 80.8 (16.0)
Niva & Skär (2006) Sweden Case control study	Private	5 76 (11.6) 3 women, 2 men Race was not reported.	Use of mobility aid	Participants used one or more mobility aids (*n*) • Walker: 4 • Crutches: 2 • Wheelchair: 1
Park et al. (2019) Korea Cross-sectional study	Private and collective	Private: 63 70.98 (6.92) 43 women, 20 men 79.4% white Collective: 85 77.46 (8.17) 58 women, 27 men 95.3% white	Chronic conditions	Number of chronic conditions • Private: 0.8 (0.8) • Collective: 1.8 (1.1)
Patry et al. (2019) Canada Cross-sectional study	Private	35 66 (4.69) 35 women Race was not reported.	Functional limitations	28/35 participants did not have problems with their functional ability
Perez-Hernandez (2018) Spain Cross-sectional study	Private	No problems with housing: 767 71.6 (0.2) 50.9% men Problems with housing: 835 71.3 (0.2) 47.0% men Race was not reported.	Short Physical Performance Battery (SPPB)[d]	SPPB Score • Baseline: 8.5 (2.5) • Follow-up after 5 years: 8.6 (2.4)
Petersson et al. (2012) Sweden Explorative qualitative study	Private	8 75 (15.7) 4 women, 4 men Race was not reported.	Chronic conditions	All participants had one or more chronic conditions (e.g., cardiovascular disease, blood pressure, stroke, arthritis)
Pettigrew et al. (2020) Australia Cross-sectional study	Private and collective	Separate house: 315 69.6 (5.7) 53% women, 47% men Town house: 23 69.3 (5.9) 70% women, 30% men Flat/unit/apartment: 47 71.43 (5.45) 62% women, 38% men Collective: 45 74.73 (6.75) 60% women, 40% men Race was not reported.	Chronic conditions	Participants with 0–2 chronic conditions (%) • Separate house: 56 • Town house: 39 • Flat/unit/apartment: 43 • Collective: 56
Portegijs et al. (2017) Finland Cohort study	Private	Participants engaged in physical activity outside of the home daily: 709 79.7, 7.0 (median, IQR) 60% women, 40% men Participants did not	Short Physical Performance Battery (SPPB)[d]	SPPB Score (median, IQR) • Participants moved out of the home daily: 11, 3 • Participants moved out of the home less than daily: 9, 6

(Continued)

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Table 2. *Continued*

First Author and Year, Country, Study Design	Type of Dwelling[a]	*n*, Age (years), Gender, Race	Mobility Instruments[b]	Mobility Status[b]
		engage in physical activity outside of the home less than daily: 127 83.1, 6.1 (median, IQR) 75% women, 25% men Race was not reported.		
Regan et al. (2016) Canada Pre-post study	Transition to collective dwelling	12 84.7 (4.0) 5 women, 7 men Race was not reported.	Use of mobility aid	4 participants use mobility aids
Reid (2004) Canada Cross-sectional study	Private	19 67.4 (12.3) 9 women, 10 men 18 white, 1 Asian	Use of mobility aid	Participants using mobility aids (*n*) • Cane: 12 • Wheelchair: 9 • Walker: 4 • Leg brace: 3
Thordardottir et al. (2020) Sweden Longitudinal study	Private	11 71, 45–95 (mean, range) 6 women, 5 men Race was not reported.	Use of mobility aid	8 participants use mobility aids inside the home

van den Hombergh et al. (1995)
The Netherlands
Cross-sectional study
	Private	996
		65–84 (range)
		503 women, 493 men
		Race was not reported.
			Physical disability	Presence of physical disability by different levels of physical activity across gender (*n*)
				• Women
				  • Low: 98/100
				  • Medium: 77/302
				  • High: 58/101
				• Men
				  • Low: 94/99
				  • Medium: 73/295
				  • High: 59/99

Voss et al. (2020) Canada Qualitative description approach study	Collective	31 83.5 (6.5) 26 women, 5 men Race was not reported.	Use of mobility aid	4 participants use wheelchairs

Note. Only mean (SD) values were included unless specified.
[a]We stratified studies by private, collective, or transition to collective dwelling. Private dwellings are either rented or owned property in the community (Statistics Canada, 2017b; U.S. Department of Health and Human Services, n.d). Collective dwellings include units where one lives amongst a collective of other older adults who receive support services (BC Seniors Living Association, 2021; Province of British Columbia, 2021; Statistics Canada, 2017a). If the study were observing older adults when they lived in a private dwelling and after they moved to a collective dwelling, we classified it as transition to collective dwelling.
[b]The instruments used to evaluate mobility along with the results are included. If specific instruments were not used, we reported available data on whether participants used mobility aids and on the prevalence of chronic conditions.
[c]Iwarsson & Slaug, 2001.
[d]McDowell and Newell, 1996.
[e]We only report data for participants who completed the Short Physical Performance Battery.
[f]Guralnik et al., 1994.IQR = interquartile range; SD = standard deviation.

participants in private dwellings was from 25 to 65 years, and for people in collective dwellings it was from 65 to 97 years.

Physical Activity and Sedentary Behaviour

Physical activity outcomes were reported by 21 studies (Aplin et al., 2015; Benzinger et al., 2014; Cheng et al., 2014; Cress et al., 2011; Haney et al., 2018; Harrison et al., 2010; Joseph et al., 2005; Joseph & Zimring, 2007; Lilja & Borell, 1997; Nathan et al., 2014a,b; Niva & Skär, 2006; Park et al., 2019; Patry et al., 2019; Perez-Hernandez et al., 2018; Petersson et al., 2012; Pettigrew et al., 2020; Portegijs et al., 2017; Regan et al., 2016; Reid, 2004; Thordardottir et al., 2020; van den Hombergh et al., 1995). Only three studies reported sedentary behaviour outcomes (Kotlarczyk et al., 2020; Perez-Hernandez et al., 2018; Voss et al., 2020); therefore, we concentrated more on physical activity outcomes. Tables 4 and 5 present information on quantitative physical activity and sedentary behaviour outcomes, including objective and self-report measures, for cross-sectional and pre-post studies.

Studies used accelerometry to report physical activity using the following activity monitors: ActiGraph GT1M (Nathan et al., 2014a,b), GT3X (Pettigrew et al., 2020), GT3X+ (ActiGraph Corp., Pensacola, FL) (Park et al., 2019; Regan et al., 2016), StepWatch 3.1 (Cyma, Corp., Mountlake Terrace, WA) (Cress et al., 2011); and the SenseWear Armband (BodyMedia, Pittsburgh, PA) (Patry et al., 2019). Participants in collective dwellings engaged in moderate to vigorous physical activity, such as from 77.0 minutes per week (median) (Nathan et al., 2014a) to 139.7 minutes per week (mean)

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Table 3. Quality of included studies according to Qualsyst

Study Type[a]	First Author and Year	Qualsyst Score
Qualitative	Aplin et al. (2015)	0.90
	Haney et al. (2018)	0.85
	Petersson et al. (2012)	0.90
	Thordardottir et al. (2020)	0.95
	Voss et al. (2020)	1.00
	Kotlarczyk et al. (2020)	0.90
Quantitative	Benzinger et al. (2014)	0.86
	Cheng et al. (2014)	0.92
	Cress et al. (2011)	0.91
	Harrison et al. (2010)	1.00
	Joseph et al. (2005)	0.95
	Joseph & Zimring (2007)	0.95
	Lilja & Borell (1997)	0.90
	Nathan et al. (2014a, 2014b)	1.00
	Niva & Skär (2006)	1.00
	Park et al. (2019)	0.91
	Patry et al. (2019)	0.95
	Perez-Hernandez et al. (2018)	1.00
	Pettigrew et al. (2020)	0.91
	Portegijs et al. (2017)	1.00
	Regan et al. (2016)	0.91
	van den Hombergh et al. (1995)	1.00
Mixed methods	Reid (2004)	Qualitative score: 0.45 Quantitative score: 0.65

Note. The Standard Quality Assessment Criteria for Evaluating Primary Research Papers (Qualsyst) was used to evaluate the quality of included studies (Kmet et al., 2004). The minimum score is 0.00 and the maximum score is 1.00.
[a]Study type designates whether the study design was qualitative, quantitative, or mixed methods. Qualsyst has different evaluation criteria for each study type. If the study is mixed methods, the study must be evaluated using both qualitative and quantitative criteria, resulting in two scores.

in another study (Pettigrew et al., 2020). Studies reported that older adults in private dwelling spent more time participating in light (Park et al., 2019) and moderate to vigorous physical activity (Park et al., 2019; Pettigrew et al., 2020); and had greater step counts (Cress et al., 2011) than their collective dwelling counterparts (Table 4).

Self-report measures for physical activity outcomes included: validated questionnaires (e.g., Community Healthy Activities Model Program for Seniors [CHAMPS]) (Benzinger et al., 2014; Cheng et al., 2014; Cress et al., 2011; Haney et al., 2018; Harrison et al., 2010; Joseph & Zimring, 2007; Nathan et al., 2014a; Niva & Skär, 2006; Perez-Hernandez et al., 2018; Portegijs et al., 2017; van den Hombergh et al., 1995); investigator- or study-developed instruments (Cress et al., 2011; Joseph et al., 2005; Lilja & Borell, 1997; Nathan et al., 2014b); qualitative interviews (Aplin et al., 2015; Petersson et al., 2012; Reid, 2004; Thordardottir et al., 2020) and focus groups on sedentary behaviour (Kotlarczyk et al., 2020; Voss et al., 2020. In one study, the International Physical Activity Questionnaire (IPAQ) (Craig et al., 2003) was used to determine that approximately 79 per cent of participants were sufficiently or highly active (Joseph & Zimring, 2007). According to the CHAMPS (Stewart et al., 2001), older adults from another study participated in exercise approximately 16 times a week (Haney et al., 2018).

After moving into a collective dwelling, for some participants, the percent of daytime physical activity decreased (13.3–10.2%) and sedentary behaviour increased (86.7–89.7%) (Regan et al., 2016). Prior to home modifications, older adults spent 5.5 hours performing leisure activities, which increased to 7.5 hours after renovations (Niva & Skär, 2006). The study also found that time spent at rest decreased from 11.5 hours to 9.0 hours (Niva & Skär, 2006).

Indoor Features by Domains

We categorized indoor environment features into the following three domains: campus, building, and fixtures. Figure 2 provides a summary of data synthesis. The campus domain encompassed features of the collective dwelling incorporating aesthetics and visibility, amenities and recreation, destinations, and outdoor pathways. The building domain included the following indoor features: area, floor level, and type of dwelling. The fixture domain consisted of the following features: elevators; indoor hallways; and stairs and

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Table 4. Quantitative outcomes of physical activity and sedentary behaviour for cross-sectional studies

Type of Outcome[a]	First Author and Year, Type of Dwelling[b]	Mobility Outcomes[c]	Instruments for Physical Activity and/or Sedentary Behavior[d]	Physical Activity and/or Sedentary Behaviour[d] Outcomes
Objective	Nathan et al. (2014a, b) Collective	Physical function score: 80.8 (6.0)	Accelerometry (ActiGraph GT1M)	High to light physical activity in minutes/week (median, IQR): 170.0, 153.5 Moderate to vigorous physical activity in minutes/week (median, IQR): 77.0, 136.5
	Park et al. (2019) Private and collective	Number of chronic conditions • Private: 0.8 (0.8) • Collective: 1.8 (1.1)	Accelerometry (ActiGraph GT3X+)	Light physical activity in percentage of time awake: 31.6 (11.1) • Private dwelling: 36.3 (10.5) • Collective dwelling: 28.1 (10.2) Moderate to vigorous physical activity in percentage of time awake: 2.9 (2.1) • Private dwelling: 4.9 (3.4) • Collective dwelling: 1.4 (1.4)

	Pettigrew et al. (2020)
	Private and collective
		Participants with 0–2 chronic conditions (%)
		• Separate house: 56
		• Town house: 39
		• Flat/unit/apartment: 43
		• Collective: 56
			Accelerometry (ActiGraph GT3X)	Moderate to vigorous physical activity in minutes/week (mean): 211.3
				• Private dwelling:
				  • Separate house: 221.0
				  • Town house: 191.4
				  • Flat/unit/apartment: 224.0
				• Collective dwelling: 139.7

	Cress et al. (2011) Private and collective	Physical function score • Private: 73.71 (23) • Collective: 64.17 (21)	Step count (StepWatch)	Steps per day • Private dwelling (n = 31): 9,758 (3,968) • Collective dwelling (n = 30): 6,783 (2,813)
	Patry et al. (2019) Private	28/35 participants did not have problems with their functional ability.	Energy expenditure (SenseWear Armband)	1.7 (0.31) kilocalories/minute
Self-report	Benzinger et al. (2014) Private	Number of self-reported functional limitations: 2, 1–4 (mean, IQR)	PhoneFITT[e]	PhoneFITT[e] score: 53, 42-67 (median, IQR)
	Harrison et al., 2010 Private and collective	Mean physical function score • Private: 60.1 (38.8) • Collective: 51.7 (36.1)	Physical Activity Scale for the Elderly[f]	Private dwelling (n = 305): 127.6 (72.1) Collective dwelling (n = 384): 95.4 (54.0)

	Joseph & Zimring (2007)
	Collective
		Mobility aid use (n)
		• Parkview: 3/38
		• Lakeview: 3/40
		• Greenacres: 9/36
			International Physical Activity Questionnaire[g]	Physical activity levels
				• Parkview (n = 32 available data)
				  • Insufficiently active: 5
				  • Sufficiently and highly active: 27
				• Lakeview (n = 37 available data)
				  • Insufficiently active: 5
				  • Sufficiently and highly active: 32
				• Greenacres (n = 34 available data)
				  • Insufficiently active: 12
				  • Sufficiently and highly active: 22

	Joseph et al. (2005) Collective	None	Study/Investigator developed: overall physical activity levels	Participants engaged in physical activity (%) • Independent living: 43 • Assisted living: 32

(Continued)

Table 4. *Continued*

Type of Outcome[a]	First Author and Year, Type of Dwelling[b]	Mobility Outcomes[c]	Instruments for Physical Activity and/or Sedentary Behavior[d]	Physical Activity and/or Sedentary Behaviour[d] Outcomes
	Perez-Hernandez et al. (2018) Private	SPPB[h] Score • Baseline: 8.5 (2.5) • Follow-up after 5 years: 8.6 (2.4)	Sedentary behaviour (time spent watching television)	18.6–19.4 h/week of television (range)
	Portegijs et al. (2017) Private	SPPB[h] Score (median, IQR) • Participants engaged in physical activity outside of home daily: 11, 3 • Participants moved out of the home less than daily: 9, 6	Moving out of the home daily	709/848 participants move out of the home daily. 127/848 participants move out of the home less than daily.

Note. Only mean (SD) values were included unless specified.

[a]Quantitative outcomes for physical activity and/or sedentary behaviour were classified as either objective or self-report measures. Objective measures use tools (e.g., accelerometers) to report physical activity and/or sedentary behaviour, and can include accelerometry, step count, and energy expenditure. Self-report measures are when participants are asked to report their own physical activity and/or sedentary behaviour through questionnaires or surveys.

[b]We stratified studies by private, collective, or transition to collective dwelling. Private dwellings are either rented or owned property in the community (Statistics Canada, 2017b; U.S. Department of Health and Human Services, n.d). Collective dwellings include units where one lives amongst a collective of other older adults who receive support services (BC Seniors Living Association, 2021; Province of British Columbia, 2021; Statistics Canada, 2017a). If the study were observing older adults when they lived in a private dwelling and after they moved to a collective dwelling, we classified it as transition to collective dwelling.

[c]If specific mobility instruments were not used (e.g., SPPB), we reported available data on whether participants used mobility aids and on the prevalence of chronic conditions according to their study groups.

[d]Only quantitative physical activity and sedentary behaviour data were included. Specific instruments (e.g., CHAMPS), accelerometry, step count, energy expenditure, and study/investigator-developed outcomes were reported only. We defined "physical activity" as energy expenditure by skeletal muscles (World Health Organization, 2020b) through various types of activities (e.g., household tasks, sports, exercise) (Caspersen et al., 1985). Sedentary behaviour was defined as "energy expenditure $\leq$ 1.5 metabolic equivalents of task (METs), while in a sitting, reclining or lying posture" (Sedentary Behaviour Research Network, 2012, p. 1).

[e]Gill, Jones, Zou, & Speechley (2008).

[f]Washburn, Smith, Jette, & Janney (1993).

[g]Craig et al., 2003.

[h]Guralnik et al., 1994.

IQR = interquartile range; SD = standard deviation; SPPB = Short Physical Performance Battery; CHAMPS = Community Healthy Activities Model Program for Seniors.

Table 5. Quantitative outcomes of physical activity and sedentary behaviour for pre-post studies

Type of Outcome[a]	First Author and Year, Type of Dwelling[b]	Mobility Outcomes[c]	Instruments for Physical Activity and/or Sedentary Behaviour[d]	Physical Activity and/or Sedentary Behaviour Outcomes[d]
Objective	Regan et al. (2016) Transition to collective dwelling	4 participants use mobility aids.	Accelerometry (ActiGraph GT3X+)	Physical activity in percent of daytime • Before transition to collective dwelling: • Sedentary: 86.7 (5.2) • Light: 9.4 (3.2) • Moderate/vigorous: 3.9 (2.4) • Total: 13.3 (5.2) • After transition to collective dwelling: • Sedentary: 89.7 (3.9) • Light: 7.1 (2.5) • Moderate/vigorous: 3.1 (2.1) • Total: 10.2 (3.9)
Self-report	Cheng et al. (2014) Collective	42.8% use scooter. 4.8% use wheelchair, walker, or crutch.	Modified Baecke Questionnaire (MBQ)[e]	MBQ for participants in ground-level residence • Pre-test • Household activity: 1.3 (0.6) • Leisure and sports: 1.5 (3.3) • Total physical activity: 2.8 (3.5) • Post-test • Household activity: 0.7 (0.5) • Leisure and sports: 0.2 (0.7) • Total physical activity: 0.9 (0.9) MBQ for participants in high rise residence • Pre-test (prior to move, residing in ground level units) • Household activity: 1.1 (0.6) • Leisure and sports: 1.4 (3.2) • Total physical activity: 2.5 (3.4) • Post-test (after moving to high rise units) • Household activity: 0.5 (0.4) • Leisure and sports: 0.4 (1.6) • Total physical activity: 0.9 (1.7)
	Haney et al. (2018) Transition to collective dwelling	Not reported	CHAMPS[f]	Frequency per week of exercise activities at baseline: 16.3 (16.2)
	Niva & Skär (2006) Private	Participants used one or more mobility aids: • Walker: 4 • Crutches: 2 • Wheelchair: 1	Occupational Questionnaire[g]	Time spent in activities over 24-hour day • Before home adaptation: 7 h daily living tasks, 5.5 h leisure, 11.5 h rest • After home adaptation: 7.5 h daily living tasks, 7.5 h leisure, 9 h rest

Note. Only mean (SD) values were included unless specified.
[a]Quantitative outcomes for physical activity and/or sedentary behaviour were classified as either objective or self-report measures. Objective measures use tools (e.g., accelerometers) to report physical activity and/or sedentary behaviour, and can include accelerometry, step count, and energy expenditure. Self-report measures are when participants are asked to report their own physical activity and/or sedentary behaviour through questionnaires or surveys.
[b]We stratified studies by private, collective, or transition to collective dwelling. Private dwellings are either rented or owned property in the community (Statistics Canada, 2017b; U.S. Department of Health and Human Services, n.d). Collective dwellings include units where one lives amongst a collective of other older adults who receive support services (BC Seniors Living Association, 2021; Province of British Columbia, 2021; Statistics Canada, 2017a). If the study were observing older adults when they lived in a private dwelling and after they moved to a collective dwelling, we classified it as transition to collective dwelling.
[c]If specific mobility instruments were not used (e.g., SPPB), we reported available data on whether participants used mobility aids and on the prevalence of chronic conditions according to their study groups.
[d]Only quantitative physical activity and sedentary behaviour data were included. Specific instruments (e.g., CHAMPS), accelerometry, step count, energy expenditure, and study/investigator developed outcomes were reported only. We defined "physical activity" as energy expenditure by skeletal muscles (World Health Organization, 2020b) through various types of activities (e.g., household tasks, sports, exercise) (Caspersen et al., 1985). Sedentary behaviour was defined as "energy expenditure ≤ 1.5 metabolic equivalents of task (METs), while in a sitting, reclining, or lying posture" (Sedentary Behaviour Research Network, 2012, p. 1).
[e]Baecke, et al., 1982; Emplaincourt et al., 1997; Voorrips et al., 1991.
[f]Stewart et al., 2001.
[g]Kielhofner 2002.
SD = standard deviation; SPPB = Short Physical Performance Battery; CHAMPS = Community Healthy Activities Model Program for Seniors.

ramps. Tables 6 and 7 describe how features were associated with physical activity and/or sedentary behavior.

Campus

Aesthetics and visibility

One study observed that older adults who perceived the retirement village campus as "more aesthetically pleasing features (i.e., having more trees, greenery, and pleasant natural features) were more likely to engage in more leisure walking" (Nathan et al., 2014b, p. 10), whereas another study reported that the visibility of outdoor features (e.g., courtyards) was associated with uptake of physical activity (e.g., walking in the courtyard) (Joseph et al., 2005).

Amenities and recreation

Facilities offered amenities, recreational resources and/or activities (e.g., pools) (Haney et al., 2018; Joseph et al., 2005), exercise classes (Haney et al., 2018; Regan et al., 2016), trips and scavenger hunts (Voss et al., 2020), and support for older adults to participate in physical activity (Haney et al., 2018; Joseph et al., 2005; Joseph &

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Table 6. Influence of fixtures on activity

First Author and Year, Type of Dwelling	Indoor Features	Fixtures Enabling Activity[a]	Fixtures Limiting Activity[a]
Aplin et al. (2015) Private	Door/entrance, inside home	Home adaptations	• Unsafe and/or unfinished adaptions • Ramp or stairs affected by weather conditions
Benzinger et al. (2014) Private	Inside home	Not discussed	• Needing to use hands for intricate features (locks, windows, appliances) • Inappropriate resting places or surfaces, for working while sitting • Access to garbage disposal restricted by difference in threshold or steps • Narrow doors • High difference in threshold or steps
Haney et al. (2018) Transition to collective dwelling	Type of dwelling	Amenities and recreation (e.g., aquafit, group exercise)	No longer able to pursue activities (e.g., gardening)
Kotlarczyk et al. (2020) Collective	Adjacent environment[b], inside home	• Walking to meals • Hallways with signage about length of hallway • Gym	• Unsafe sidewalks (uneven level, pebbles) • Lack of required household maintenance
Perez-Hernandez et al. (2018) Private	Adjacent environment, door/entrance, inside home	Not discussed	Lack of elevator
Portegijs et al. (2017) Private	Adjacent environment, door/entrance	Not discussed	• High-rise urban areas • Barriers at entrance
Reid (2004) Private	Adjacent environment, door/entrance, inside home	Not discussed	• Uneven floor/ground inside/outside • Narrow stairs with no handrails • Steep stairs • Long driveways • Steep ramps • Poor lighting • Heavy doors • Narrow doors • Keyholes placed high • Unable to access some (e.g., basement) • Water on balconies • Lack of wheelchair accessibility (placement of cupboards, non-accessible bathtubs, sharp angles, small area of rooms)
Thordardottir et al. (2020) Private	Door/entrance, inside home	• Ramps • Grab bar at entrance • Increasing area of bathroom and kitchen • Replace bathtubs with showers • Stove timer • Stair lift • Wider doors • No indoor thresholds	• No grab bars at entrance • Difference in floor level • High thresholds • Heavy doors
van den Hombergh et al. (1995) Private	Inside home	• Housing on the second floor or above • Housing with stairs	• One story, ground level housing • Housing with elevators

Note. This table provides further information on how the indoor features within the *fixtures* domain affects physical activity. This domain applies to both private and collective dwellings.
[a]"Activity" is defined as physical activity, which is energy expenditure by skeletal muscles (World Health Organization, 2020b) through various types of activities (e.g., household tasks, sports, exercise) (Caspersen et al., 1985).
[b]Adjacent environment includes spaces immediately outside the residential area, such as hallways, gardens, backyards, and front lawns (Peel et al., 2005).

Zimring, 2007; Kotlarczyk et al., 2020; Nathan et al., 2014a,b; Regan et al., 2016; Voss et al., 2020). Two studies demonstrated that a lack of amenities or activities limited older adults' participation in physical activity (Joseph et al., 2005; Voss et al., 2020). In contrast, access to amenities resulted in less opportunity to engage in ADLs, which may reduce light activities and increase sedentary behaviors (Kotlarczyk et al., 2020).

Destinations

Destinations, including on-site gardens (Joseph et al., 2005), local shops, and clubhouses (Nathan et al., 2014a,b) promoted physical activity. Two studies reported that dining halls or similar destinations for eating meals encouraged walking (Kotlarczyk et al., 2020; Voss et al., 2020), but also resulted in longer periods of sedentary time while older adults were served meals (Kotlarczyk et al., 2020).

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Table 7. Influence of campus on activity

First Author and Year, Type of Dwelling	Indoor Features	Campus Features Enabling Activity[a]	Campus Features Limiting Activity[a]
Cress et al. (2011) Private and collective	Size of living space between dwelling types	Larger living spaces and private dwelling	Smaller living spaces and collective dwelling
Joseph & Zimring (2007) Collective	Campus features	• Paths with destinations related to residence, activities, or administration building(s) • Connectedness of path • Aesthetically pleasing paths (nature, art-work) • Longer paths • Indoor hallways during bad weather • Paths without steps/stairs • Steep paths	• Shorter paths • Paths with steps/stairs
Joseph et al. (2005) Collective	Campus features	• Outdoor features: paths, gardens, outdoor amenities, and recreation (e.g., lawn bowling) • Visibility of outdoor features • Indoor amenities and recreation (e.g., indoor pool)	Lack of indoor/outdoor amenities and recreation
Kotlarczyk et al. (2020) Collective	Campus features, inside unit	• Need to walk to meals • Hallways with signage about length of hallway • Gym	• Unsafe sidewalks (uneven level, pebbles) • Lack of required household maintenance
Nathan et al. (2014a, b) Collective	Campus features	• Smaller campus area • Recreational facilities • Infrastructure which supports walking • Aesthetics • Presence of clubhouse	• Larger campus area • Presence of aged care facility
Voss et al. (2020) Collective	Campus features	• Need to walk to meals • Hallways • Activities (e.g., scavenger hunts)	• Smaller area of rooms • Lack of amenities and recreation activities

Note. This table provides further information on how the indoor features within the campus domain affect physical activity. This domain applies to collective dwellings only.
[a]"Activity" is defined as physical activity, which is energy expenditure by skeletal muscles (World Health Organization, 2020b) through various types of activities (e.g., household tasks, sports, exercise) (Caspersen et al., 1985).

Outdoor pathways

Older adults observed that well-planned and connected paths influenced walking (Joseph & Zimring, 2007). Longer path lengths, steep paths, and campuses with hills were associated with increased participation in recreational walking (Joseph & Zimring, 2007).

Building

Area

Two studies observed that smaller spaces limited physical activity (Reid, 2004; Voss et al., 2020), and that renovations (e.g., bathroom expansions in private dwellings) increased engagement in ADLs (e.g. showering) (Thordardottir et al., 2020). However, older adults experienced difficulties navigating and engaging in physical activity when retirement villages were too large (Nathan et al., 2014a,b).

Floor level

In private dwellings, high rise urban areas restricted physical activity (Portegijs et al., 2017), and older adults had trouble moving between apartment floors (Lilja & Borell, 1997), whereas one-story, ground level houses were associated with increased physical activity (van den Hombergh et al., 1995). Another study found no observed evidence between the apartment floor level and physical activity of older adults residing in high-rise retirement communities (Cheng et al., 2014).

Type of dwelling

There were differences in physical activity engagement across different dwellings. For example, older adults living in private dwellings participated in more physical activity (Harrison et al., 2010; Park et al., 2019; Pettigrew et al., 2020),whereas some older adults in collective dwellings participated in less physical activity (Cress et al., 2011; Harrison et al., 2010; Pettigrew et al., 2020). After relocating to a collective dwelling, older adults reported an increase in sedentary behaviours (Kotlarczyk et al., 2020).

Fixtures

Elevators

Lack of access to an elevator restricted physical activity (Perez-Hernandez et al., 2018), whereas another study found that elevators limited physical activity (van den Hombergh et al., 1995).

Indoor hallways

In collective dwellings, indoor hallways promoted walking (Voss et al., 2020), and older adults preferred to have "signs indicating the length of hallways as a way for residents to track their progress while walking" (Kotlarczyk et al., 2020, p. 8).

Stairs and ramps

Older adults reported restrictions when participating in physical activity because of narrow stairs without hand rails, high steps, steep ramps (Reid, 2004), and high threshold or step difference (Benzinger et al., 2014). These features also restricted access to spaces (e.g., waste disposal bins) (Benzinger et al., 2014). Conversely, ramps enabled physical activity (Thordardottir et al., 2020).

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Cross-cutting domains

Accessibility

Niva and Skär (2006) observed that the following modifications increased accessibility: removal of thresholds, new taps in the bathroom and kitchen, and wider doorways. Some housing features limited accessibility: narrow doors or doorways (Benzinger et al., 2014; Niva & Skär, 2006; Reid, 2004), heavy doors (Reid, 2004), and thresholds and room design (Niva & Skär, 2006). One study also discussed mobility limitations from insufficient "places to grab onto to help [older adults] through the entrance" (Reid, 2004, p. 206).

Safety and environmental hazards

Safety and environmental hazards were identified as limiting physical activity for older adults. Kotlarczyk et al. (2020) reported that pebbles and uneven sidewalks prevented older adults from walking outside in collective dwellings. In private dwellings, Reid (2004) found that the following safety and environmental hazards limited physical activity: uneven flagstones, cement, and floor; narrow stairs without handrails; long driveways or steep ramps; heavy doors; and water on balconies. Two studies also reported that safety affected participation in ADLs (Petersson et al., 2012; Thordardottir et al., 2020); and that improving safety through house modifications could enable older adults to engage in ADLs (Thordardottir et al., 2020).

Discussion

This systematic review synthesizes evidence for a relationship between the indoor environment and physical activity in older adults. We found limited evidence for sedentary behaviour, but identified features of the relationship between the indoor environment and physical activity across three domains: campus, building, and fixtures. Features which enabled physical activity in the campus domain were: aesthetics (Nathan et al., 2014a,b), outdoor features (Joseph et al., 2005), amenities and recreation (Haney et al., 2018; Joseph et al., 2005; Joseph & Zimring, 2007; Kotlarczyk et al., 2020; Nathan et al., 2014a,b; Regan et al., 2016; Voss et al., 2020), and destinations (Joseph et al., 2005; Kotlarczyk et al., 2020; Nathan et al., 2014a,b; Voss et al., 2020). Absence of amenities and recreational resources limited physical activity (Joseph et al., 2005; Voss et al., 2020). However, the presence of dining halls and some amenities promoted sedentary behaviour by reducing the opportunity to engage in ADLs (Kotlarczyk et al., 2020). For the building domain, greater area (Thordardottir et al., 2020), ground level housing (van den Hombergh et al., 1995), and private dwellings (Harrison et al., 2010; Park et al., 2019; Pettigrew et al., 2020) promoted physical activity. Sedentary behaviour reportedly increased after transition to a collective dwelling (Kotlarczyk et al., 2020). The following features hindered physical activity in the building domain: smaller area (Reid, 2004; Voss et al., 2020), larger retirement village campuses (Nathan et al., 2014a,b), high-rise buildings (Lilja & Borell, 1997; Portegijs et al., 2017), and collective dwellings (Cress et al., 2011; Harrison et al., 2010; Pettigrew et al., 2020). In the last domain, fixtures which supported physical activity included indoor hallways (Kotlarczyk et al., 2020; Voss et al., 2020), and ramps (Thordardottir et al., 2020). Stairs which were narrow and without handrails, steep ramps (Reid, 2004), and high threshold or step differences (Benzinger et al., 2014) restricted physical activity. The presence of elevators (van den Hombergh et al., 1995), along with the lack of access to elevators (Perez-Hernandez et al., 2018), also limited physical activity. Indoor features related to safety and environmental hazards also impeded engagement in physical activity, such as uneven floors (Kotlarczyk et al., 2020; Reid, 2004).

Our review observed that the availability of amenities and recreational resources, such as golf courses and pools, can increase participation in physical activity for older adults living in collective dwellings (Haney et al., 2018; Joseph et al., 2005; Joseph & Zimring, 2007; Kotlarczyk et al., 2020; Nathan et al., 2014a,b; Regan et al., 2016; Voss et al., 2020). Another systematic review highlighted how the type of facility can affect sedentary behaviour: amenities related to exercise were associated with lower sedentary behaviour, whereas socialization or educational activities (e.g., salons, music rooms) were associated with greater sedentary behaviour (Ahrentzen & Tural, 2015). Despite access to these resources, other work observed that only half of the amenities were used by older adults living in retirement villages (Holt, Lee, Jancey, Kerr, & Howat, 2016). This finding suggests that simply increasing the number of and/or access to amenities is not enough to increase uptake of physical activity. The Model of Human Occupation proposes that volition (characterized by people's values and interests) can affect engagement in activities (Kielhofner & Burke, 1980). Specifically, people are more likely to engage in activities that they find meaningful (Kielhofner & Burke, 1980). Behaviour strategies and identification of possible barriers to and facilitators of physical activity engagement should also be considered (Jancey et al., 2008). Evidence suggests that peer leaders, staff, or facilitators are more influential in the uptake of physical activity, than is access to recreational amenities (Ahrentzen & Tural, 2015; Dorgo et al., 2009; Jancey et al., 2008 as cited in Holt et al., 2016;). Therefore, it simply may not be enough to build facilities. The social environment and other behaviour strategies play a role in the adoption and maintenance of physical activity (Annear et al., 2014).

Ahrentzen and Tural (2015) included people with dementia in their systematic review of active aging across dwellings. Similar to our findings, their review observed that steep ramps hindered physical activity (Ahrentzen & Tural, 2015). They also noted higher step counts were associated with larger areas and communal dwellings, whereas home modifications enabled participation in ADLs (Ahrentzen & Tural, 2015), which are consistent with our findings. The review (Ahrentzen & Tural, 2015) had more results for sedentary behaviour, reporting that the frequency of indoor hallways was associated with less sedentary behaviour (Kerr et al., 2011 as cited in Ahrentzen & Tural, 2015). Another review found that the "smoothness" of paths, accessibility, and safety increased participation in physical activity (Annear et al., 2014). However, the review reported that "poor-quality" (p. 602) pathways served as a barrier to physical activity (Annear et al., 2014), which our review did not find. However, these differences may be because of the different populations under study: one review included people with dementia (Ahrentzen & Tural, 2015), and other reviews studied the implications of social and societal effects (e.g., relationships with staff working at collective dwellings, poverty) (Ahrentzen & Tural, 2015; Annear et al., 2014).

We observed several illustrations of the connection between the older adult and their environment. Different settings could potentially support specific types of physical activity: Older adults in collective dwellings often do not engage in as many ADLs because they receive services from the facility (e.g., prepared meals reduce the need to cook) (Kotlarczyk et al., 2020). Similarly, older adults can influence their environments. For example, when older adults move to collective dwellings because of functional decline (Crisp, Windsor, Butterworth, & Anstey, 2013), they often move into a

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space smaller than their previous private dwelling (Hansen & Gottschalk, 2006). Another study observed that hills promoted recreational physical activity (Joseph & Zimring, 2007), whereas some evidence demonstrates challenges with using hills on campus (Holt et al., 2016). Perez-Hernandez et al. (2018) noted that lack of access to elevators restricted physical activity (Perez-Hernandez et al., 2018), whereas van den Hombergh et al. (1995) found that elevators limited physical activity (van den Hombergh et al., 1995). This discrepancy may be explained in two ways: lack of access to elevators restricts the frequency of older adults leaving their homes, resulting in decreased physical activity; and/or access to elevators results in reduced use of stairs, which could also impact overall physical activity. Elevators and stairs are dependent on people's mobility. For those without restrictions, stairs can help maintain physical activity and function.

The intricate relationship between older adults and their environments can be understood through the Canadian Model of Occupational Performance and Engagement (CMOP-E) (Law et al., 1977; Townsend & Polatajko, 2007) and the person–environment fit framework (Su, Murdock, & Rounds, 2015). The CMOP-E explains how the person, environment, and occupation (defined as a person's role in an environment [Warren, 2002]) interact when people are engaging in various behaviours (Law et al., 1977; Townsend & Polatajko, 2007). The person–environment fit framework suggests that "people shape their environments and environments shape people" (Rounds & Tracey, 1990 as cited in Su et al., 2015, p. 83). The CMOP-E and person–environment fit apply here, such as how functional decline can result in an older adult moving into a smaller home (Crisp et al., 2013; Hansen & Gottschalk, 2006), which may not provide as many opportunities for physical activity (Reid, 2004; Voss et al., 2020).

Accessibility and safety were cross-cutting domains because they can impact multiple levels (campus, building, and fixtures) of the indoor environment. Evidence suggests that limitations in accessibility are negatively correlated with physical activity in adults with disabilities (Saebu, 2010). Older adults in both private and collective dwellings reported that hazards such as uneven grounds or floors prevented participation in physical activity (Kotlarczyk et al., 2020; Reid, 2004). This finding is supported by other evidence which report that "obstructions on the pathway" (Holt et al., 2016, p. 408) were a barrier to walking in collective dwellings (Holt et al., 2016). Private dwellings often require modifications, such as the installation of ramps or grab bars, to increase both accessibility and safety (Niva & Skär, 2006; Thordardottir et al., 2020), demonstrating their synergistic relationship, and can encourage engagement in ADLs (Ahrentzen & Tural, 2015). Accessibility and safety are integral to Universal Design principles (Connell et al., 1997; Null, 2013a).

The findings from this synthesis align well with the seven principles of Universal Design (Null, 2013b): "products, environments, programmes and services to be usable by all people… without the need for adaptation or specialized design" (Office of the United Nations High Commissioner for Human Rights, 2021). Housing and campus design should consider that features such as safety and aesthetics (Equitable Use), how older adults choose to use outdoor campus pathways (Flexibility of Use), minimizing hazards such as uneven floors (Error Tolerance), managing heavy doors (Reid, 2004; Thordardottir et al., 2020) (Physical Effort), and living space (Size and Space for Approach and Use) may influence older adult's participation in physical activity (Nathan et al., 2014a, b; Reid, 2004; Thordardottir et al., 2020; Voss et al., 2020). Universal Design principles coincide with the Global Age-Friendly Cities Project (World Health Organization, 2010). Older adults sometimes reside in older housing which may require retrofitting according to Universal Design principles. Although designing activity-friendly housing from the beginning is ideal, initiatives such as Complete Streets (for outdoor environments) (Transport Canada, 2009, p. 1), provides an example of retrofitted infrastructure to accommodate all people, and could be considered within the housing sector to promote healthy, active aging in place.

Strengths and Limitations

Our study included all studies regardless of language, dwelling, or study design. Because our review only included studies from higher income countries, the results may not be representative of other regions. Only a limited number of studies reported data on race/ethnicity; therefore, the findings may not be generalizable.

The inclusion of both qualitative and quantitative studies strengthened our review, as we could draw upon different data. Although only one author extracted data, we tried to mitigate risk by having a second author review and complete data extraction for 10 per cent of the studies. Our review did not exclude studies of low quality; however, only one study had a quality score under 0.85/1.00. Differences in physical activity engagement could arise from varying functional mobility of older adults across dwellings, and/or the level of care that older adults received in their residence (e.g., laundry services). Further, we located limited findings for indoor features and sedentary behaviour. Finally, we did not review the relationships of physical activity or sedentary behavior and (i) social environment or (i) health care costs.

Implications of the Main Findings

The findings of this synthesis could inform future housing policy. As the population of older people increases globally, governments may need to focus on providing activity-supportive housing and/or retrofitting pre-existing infrastructure to support accessibility and physical activity.

Future Research and Recommendations

Although our study explored the effects of indoor environment on physical activity and/or sedentary behaviour, future studies should take the social environment and health care costs into consideration. Future studies should investigate the relationship between the indoor environment and sedentary behavior. Understanding this relationship can assist with designing indoor environments, which may reduce prolonged periods of sedentary behaviour. We need more research to inform retrofitting existing infrastructure, physical activity, and Universal Design principles in an effective and efficient manner. In the long term, future research or policy could consider developing a rating system for evaluating physical-activity-friendly buildings for aging in place. Additional research is needed for low- and middle-income countries to improve representation and generalizability, especially as the studies included in this review were from higher-income countries. Further, for studies conducted in higher-income countries, greater diversity of study participants should be included in future research. We also encourage researchers to report data for race/ethnicity, as only four studies included these data in this synthesis.

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