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Abstract

Objectives: This article explores how the building-scale built environment is associated with self-rated health, examining differences in this association among younger, middle-aged, and older age groups. Features examined included building type, building condition, and sidewalk presence in front of dwellings. **Background:** Understanding how the relationships between built environments and health vary across age groups helps to build a healthy environment for all. However, most studies have concentrated on the neighborhood or indoor environment, rather than whole buildings, and few have compared age groups. **Methods:** This study analyzed survey data from 1,019 adults living in 40 neighborhoods in Chengdu, China, recruited through a clustered random sampling approach. It used a Bayesian logistic mixed-effects model with interaction terms between age-group indicators and other variables. **Results:** Significant differences exist in the relationships of self-rated health with some environmental and other indicators among age groups. For older people, living in multi-floor buildings, having a household smoker, and undertaking fewer hours of weekly exercise were associated with lower odds of reporting good, very good, or excellent health. These relationships were not identified among middle-aged and younger people. More education was associated with higher odds of reporting better health among older and middle-aged groups. **Conclusions:** Older people experience more health-related challenges compared to middle-aged and younger people. However, among the examined built environment factors, building type was the only significant factor related to self-rated health among older people. To promote health among older people, this study recommends adding elevators in the multi-floor buildings.

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Keywords

self-rated health, built environment, building, housing, lifestyle, older people, planning, aging in place, age-friendly

Determinants of health include several social and environmental factors and one aspect is the built environment in which people live and work. Studies to date examining the built environment and health have tended to explore larger areas such as cities and wider neighborhoods or smaller environments such as the interiors of homes, workplaces, and health facilities (Al horr et al., 2016; Gardener & Oliveira, 2020; MacAllister et al., 2016; Mujan et al., 2019). This study examines how perceived health is associated with housing quality at the building scale and for the immediate residential neighborhood focusing on different age groups while controlling for several socioeconomic factors and health behaviors. It draws on data from Chengdu, China, a location with a very wide range of housing types from single-level dwellings to mid-rise walk-ups and high-rise towers.

In exploring how environments affect health, age matters because older people may face health problems that their setting can exacerbate or ameliorate (Kan et al., 2020; Lawton & Nahemow, 1973). They may encounter mobility challenges due to visual, musculoskeletal, and cardiovascular problems (Startzell et al., 2000). Older people are more vulnerable to extreme cold and heat because they are less responsive to changes in the thermal conditions due to reduced efficiency of body mechanisms (van Hoof et al., 2017).

The population of older people is also increasing. People aged 65 and older are projected to reach 16% of the world's population by 2050, up from 8% in 2010. While developed countries have been aging for decades, the most rapidly aging societies are in developing countries (World Health Organization & National Institute on Aging, 2011). For example, in 2018, older people aged 60 and above reached 18% of the Chinese population (Dang & Li, 2019). As the parents of the single-child generation born in the 1980s enter old age, the age structure is changing. Urban migration also means that many

older people live by themselves. It is critical to adjust the environment for aging.

This article first outlines the literature on how residential buildings and their immediate vicinity are associated with health, particularly for older adults. The study used data from 1,019 adults living in 40 neighborhoods in Chengdu, China, and analyzed via descriptive and inferential statistics. The latter included a Bayesian logistic mixed-effects model with interaction terms between age-group indicators and other variables. The study concludes that better understanding the relationships between age, health, environments, and other factors can help policy makers and professionals to better target interventions to improve health and well-being.

Background

Previous research has examined how healthcare built environment factors such as access to nature and daylighting, reduced noise, room layout, and circulation design are associated with health and related outcomes (Gaminiesfahani et al., 2020; Jiang & Verderber, 2017; MacAllister et al., 2016). In contrast, work on the residential built environment has typically focused on the physical aspects of neighborhoods, transport, and natural landscapes; and access to services like food (Bird et al., 2018). Scholars have conducted numerous studies on how such built environment factors at the city and neighborhood scale were associated with health outcomes (Kerr et al., 2012; Renalds et al., 2010; Schüle & Bolte, 2015). Likewise, researchers in the fields of building science and public health have explored multiple facets of the indoor environment such as indoor air quality, thermal comfort, natural ventilation, and lighting and their effects on the health of both general populations and older people (Fisk et al., 2020; Patino & Siegel, 2018; van Hoof et al., 2017).

Limited work has been done in the residential environment on the scale that connects the neighborhood and household. For example, how do overall building conditions, access to dwellings via stairs or other means, and nearby pedestrian infrastructure such as having a sidewalk in front of one's home influence health? These factors could matter for health particularly among older people. Buildings in poor condition might be damaged, moldy, unpleasant, and could have limited daylighting, natural ventilation, and thermal comfort, which may have comprehensive mental and physical health effects. For example, Thomson et al. (2013) reviewed 39 studies and found that investment to improve housing conditions such as thermal comfort and energy efficiency can improve health. Furthermore, using a probability sample of 611 older people in Nanjing, China, Feng et al. (2018) showed that the age of the building affected the subjective well-being of older people, with newer buildings having more positive effects. Based on a sample of 1,896 older people in Delhi, India, Firdaus (2017) studied the effects of the built environment on mental health. Results showed that older people living in buildings that were in better condition, defined as not requiring immediate repairs on the structure, demonstrated better mental health.

Moreover, living in multistory buildings without elevators may hinder older residents' outdoor activities. Movement on stairs can be challenging and dangerous activities for older people. Falling is a leading cause of accidental death among older people aged 65 and above in the United States (Centers for Disease Control and Prevention, 2020). Globally, over 80% of the deaths from falls occur in low-and middle-income countries (World Health Organization, 2018). A no-step entry is one of the basic accessibility features for an age-friendly home, and older adults may reduce activities due to fear of falling (Molinsky & Forsyth, 2018). Based on movement tracking data from 64 senior participants in Shanghai, who wore a Fitbit HR for 31 consecutive days, Yu et al. (2020) investigated how the need to climb stairs in residential buildings affected the outdoor activities of older people. Results showed that participants were one third less likely to go outdoors if they lived one more floor above ground

in multistory no-elevator residential buildings. Additionally, the sidewalk in front of the residential building provides a safer connection and better accessibility to facilities in the neighborhood. It is important especially for older people who use walking assistance devices. Extensive evidence suggested that sidewalks facilitate physical activity and related health outcomes (Kerr et al., 2012; Renalds et al., 2010).

Multi-floor walk-up residential buildings are common in China. It was the major type of residential buildings constructed by the government or Danwei (government-owned enterprises) between the 1950s and 1990s (Yu et al., 2020). By now, Danwei housing is often old and poorly maintained and has relatively poorer design quality compared with commodity- or market-rate housing. After the 1990s when housing was opened to the market, real estate developers continued to build multi-floor walk-up buildings of up to six floors to maximize the density while saving building costs, since the national building code requires residential buildings of seven or more floors have elevators (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2011). While some walk-up buildings have been upgraded with features such as elevators, this is not yet common in Chengdu. To facilitate adding elevators to walk-ups, the government of Chengdu city published "Management Measures of Adding Elevators to Existing Residential Buildings in Chengdu," which came into effect on January 1, 2016 (Municipal General Office of Chengdu, 2018). However, no elevator was added to an existing multi-floor building in Chengdu until October 2018, well after the data collection for this study occurred (Chengdu Evening News, 2019).

This article aims to contribute to the limited research body on how the built environment and health are connected at the building scale in terms of building type, building condition, and adjacent sidewalks. It also emphasizes health obstacles among older people by comparing them with other age groups. Existing studies have mostly examined either the general population or the older people only. This article also provides a case in a city in China, which could offer lessons

for cities in developing and middle-income countries.

Materials and Method

Study Area

Chengdu is the capital of Sichuan Province in Southwest China and a second-tier city in contemporary China. In 2016, the administrative region of Chengdu had 15.92 million inhabitants with and without Hukou¹ (residency registration), living in a 14,335 km² (3,542,256 acres) area covering the core city, suburban districts, and counties. The core city study area includes five districts, Jinjiang, Qingyang, Jinniu, Chenghua, and Wuhou, with an area of 465 km² (114,904 acre). In 2016, the population in the core city was 3.83 million inhabitants with Hukou and 4.6–4.7 million total population including those without Hukou (Chengdu Statistic Bureau et al., 2017). Chengdu has a flat topography in its urban area and a mild climate (Brief Introduction to Geography of Chengdu, n.d.). This kind of physical environment allows outdoor activities throughout the year and does not require heating in winter.

Sampling

This study analyzes data from a household survey conducted in Chengdu in 2016. The survey was led by the Harvard-China Project at the Harvard John A. Paulson School of Engineering and Applied Sciences to investigate urban land use, transportation, public health, and related policy in Chengdu, China. It involved two questionnaires, one on public health and another on transport. This study used the former. The sampling and fieldwork were conducted by the Research Center for Contemporary China (RCCC) at Peking University in June and July 2016. The team used a clustered random sampling approach with GPS- and GIS-assisted sampling. This first divided the study area by longitude and latitude and created a pool of 986 primary sampling units (PSUs) of half-square minute of latitude and longitude. Using the 2nd Ring Road as the stratification boundary, the number of PSUs to be selected at the first stage was proportional to the population

size of each stratum. As a result, 40 PSUs, including 13 inside and 27 outside the 2nd Ring Road, were randomly selected (See Figure 1) (RCCC, 2016).

At the second stage, one 90 m × 90 m (295 ft × 295 ft) secondary sampling unit (SSU) and four backup units were randomly selected from the 80 units in each PSU. If the SSU covered a non-residential area only, a backup unit was used. At the third stage, 30–60 dwellings were randomly selected from each SSU. The health questionnaire and transportation questionnaire were used in alternating households. The qualified respondents were Chinese residents aged 18–70 who had lived at the current address for a year or longer. One interviewee was selected from each household using the Kish grid method. The questionnaires were pretested, all surveyors and interviewers were trained, and the whole data collection process was under strict quality control. In total, for the public health survey, 1,744 eligible interviewees were selected and 1,065 of them completed the interviews, obtaining a response rate of 61%. Data were made available to us after the full data collection process had been completed. It was in an anonymous file geocoded to the PSU level only for privacy reasons (RCCC, 2016). Based on the definition of human subject by the U.S. federal regulations, this article does not need approval for human subject research because it uses existing de-identified data (Electronic Code of Federal Regulations, n.d.).

The sample was compared with census data to examine the sample representativeness (Office for the Population Census of Sichuan Province & Sichuan Provincial Bureau of Statistics, 2012). Household income for participants was compared with yearbook data. As shown in Table 1, older people were overrepresented in the sample. This was not a problem in this article since the study aimed to compare age groups. Gender- and education-level distributions were similar to the census. However, populations from lower income households were likely overrepresented. Not everyone in the survey answered the question ($n = 493$) but their average household income was much lower than that of the urban households in Chengdu. The difficulty in accessing the high-end gated communities with rigid

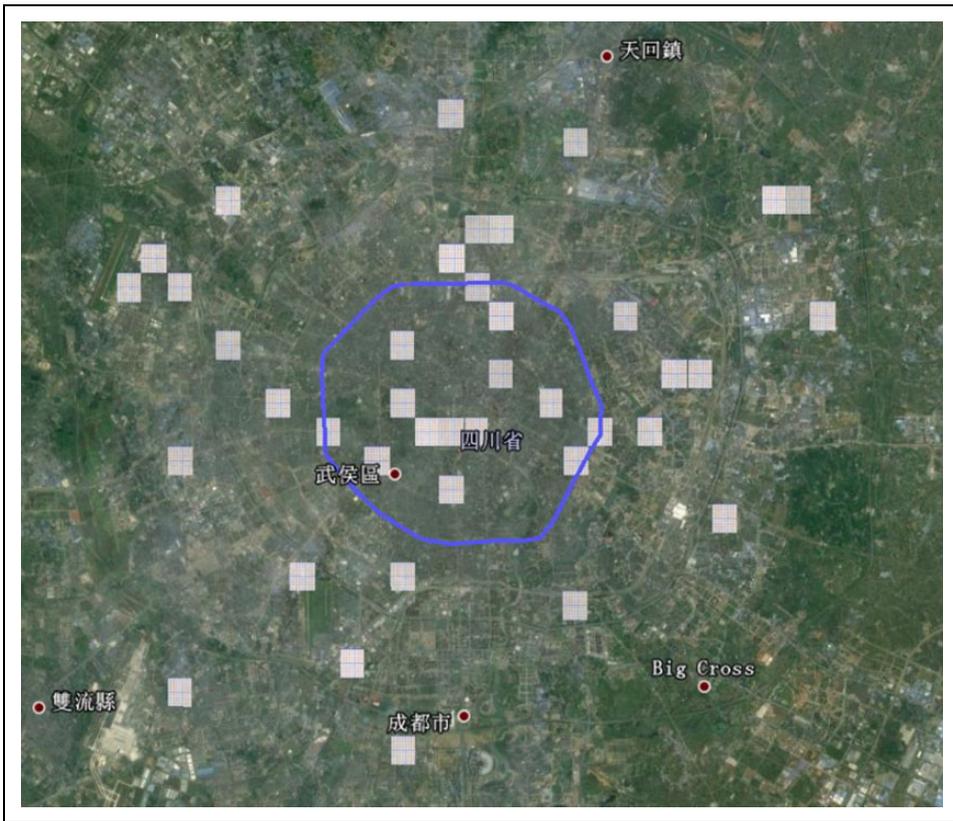


Figure 1. Distribution of the 40 selected primary sampling units in the core city of Chengdu. Note. The blue circle denotes the 2nd Ring Road that served as the stratification boundary at the first stage of sampling. Source: RCCC (2016, p. 7).

security management might have reduced the representativeness of individuals from higher income families (RCCC, 2016). Meanwhile, people may tend to underreport their income.

The data analysis in this article excluded 46 (out of 1,065) observations who had either asthma and or serious disability, injury, and chronic diseases so that they never worked or had retired because of illness. Among the 29 observations with a severe disability, injury, and chronic diseases, 100% of them reported fair or poor health status and 65% of the 20 observations with asthma had self-rated fair or poor health. Three observations overlapped among these two categories. These extreme illness situations were much less likely to be caused by the built environment. Excluding these confounding cases helped us to better understand the relationship

between the built environment and health. The sample included 1,019 observations after excluding these cases.

Variables

This article examined the relationship of self-rated health with the built environment at the building scale while controlling sociodemographics, healthy behavior, and the indoor environment. The outcome variable was self-rated health, which was measured by a single question “In general, would you say your health is excellent, very good, good, fair, or poor?” The Likert-type scale answers were recoded into a binary variable, where 1 indicated excellent, very good, and good health. Self-rated health has been found to be a valid indicator of actual health status and

Table 1. Comparing Sample With Census and Yearbook Data.

Variable	Measure	Sample	Census/ Yearbook
Age ^a (%) (among population of ages 18–70)	18–39	43.76%	51.51%
	40–59	35.96%	37.86%
	60–70	20.28%	10.63%
Gender (%)	Female	49.86%	49.85% ^b
Household income last year (RMB ¥ Yuan)		50,000–59,999 ^c	99,089 ^d
Education ^e (%)	Middle school or below	53.95%	51.99%
	High school and professional school	34.02%	37.12%
	College or above	12.03%	10.89%

^aPeople were aged 18–70 in the sample. Accordingly, we used data of ages 18–70 in the 2010 census (Office for the Population Census of Sichuan Province & Sichuan Provincial Bureau of Statistics, 2012, pp. 172–174).

^bSame source as above (p. 172).

^cOnly 493 participants answered the annual household income question by selecting a level between 0 and 18. The mean and median levels were both 11, which represented a range of ¥50,000–59,999 RMB.

^dThis is the annual disposable income of urban households in the city area of Chengdu in 2015, calculated by multiplying annual disposable income per capita by average household size (Statistical Bureau of Sichuan & NBS Survey Office in Sichuan, 2016, pp. 204, 207).

^eRefer to the 2010 census (Office for the Population Census of Sichuan Province & Sichuan Provincial Bureau of Statistics, 2012, pp. 197–202).

has been widely used in existing research on neighborhood environments and health (Wen et al., 2006).

Built environment variables included building type, building condition, and sidewalk presence in front of the home, as recorded by the interviewers. The building type question included three answers: one floor ($N = 79$) or “平房” in Chinese language,² multi-floor (two to six floors, $N = 642$) or “6层及以下楼房,” and high rise (seven floors and above, $N = 284$) or “6层以上楼房.” For the building type variable, code 1 referred to multi-floor buildings and 0 referred to the other two types to reflect the possible difficulty of accessing the multi-floor buildings due to lack of an elevator. The multi-floor buildings in Chengdu usually do not have elevators, as noted earlier. Given the lower income population in the study, this was even more likely. In high-rise buildings of seven or more floors, elevators are mandatory by building codes as previously mentioned.³ Examination of historical aerial photos of June 2016 (Google Earth) within the areas of the selected PSUs indicated that one-floor buildings were typically urban villages or

vernacular dwellings. This type is typically inhabited by lower income groups. Table 2 also shows that, compared to other types, the one-floor buildings were in worse condition on average, had a lower percentage of sidewalk presence, and their residents had fewer years of education. Building condition was subjectively evaluated using interviewers’ observations with an answer “good” “average” or “bad” compared to the average building condition in the city. The variable related to sidewalks documented whether there was a sidewalk on the road in front of the interviewee’s dwelling.

Self-reported sociodemographic variables were age, gender, and years of received education. Health behavioral variables included current smoking status and exercise hours per week. Indoor environment variables included whether the respondent reported at least one household member who was a smoker. Based on a literature review on sources of household air pollution and their impact on health, tobacco smoke is one of the major sources of household pollutants (Apte & Salvi, 2016).

Table 3 shows the descriptive characteristics of the variables in this study. Among all, 77%

Table 2. Cross-Tabulation of Building Type and Other Factors.

Variable	Measure	Sample		One Floor Total N = 79 %/Mean (Min-Max)	Multi-Floor (Two to Six Floors) Total N = 642 %/Mean (Min-Max)	High Rise (Seven Floors and More) Total N = 284 %/Mean (Min-Max)
		Total N = 1,019 ^a	%/Mean (Min-Max)			
Self-rated health	Good, very good, or excellent	1,019	77%	42 (20-70)	43 (18-70)	42 (18-70)
Age	Female	1,019	50%	7.6 (0-16)	9.9 (0-22)	10.9 (0-19)
Education	Years	1,018	35%	7.5 (0-70)	5.8 (0-56)	5.7 (0-48)
Smoking	Yes	1,017	61%	61%	62%	59%
Exercise	Hours/week	1,004	88%	71%	87%	96%
Household member smoking	At least one smoker	1,019	94%	86%	94%	99%
Building condition	Good or average	1,007				
Sidewalk presence in front of house	Yes	1,003				

^aFourteen of 1,019 observations had missing values for the building type variable.

Table 3. Descriptive Characteristics of the Sample Population.

Variable	Measure	Sample		Young		Middle-Aged		Older	
		N	% ^a /Mean (Min–Max)	Total N = 461	%/Mean (Min–Max)	Total N = 366	%/Mean (Min–Max)	Total N = 192	%/Mean (Min–Max)
Self-rated health ^b	Good, very good, or excellent	1,019	77%	28 (18–39)	91%	48 (40–59)	73%	65 (60–70)	53%
Age		1,019	43 (18–70)						
Gender	Female	1,019	50%	48%		52%		52%	
Education	Years	1,018	10.0 (0–22)	12.7 (5–22)		8.5 (0–19)		6.3 (0–16)	
Smoking	Yes	1,017	35%	37%		36%		29%	
Exercise	Hours/week	1,004	5.9 (0–70)	5.4 (0–70)		5.2 (0–56)		8.4 (0–48)	
Household member smoking	At least one smoker	1,019	61%	60%		67%		51%	
Building type ^c	Multi-floor	1,005	64%	63%		66%		62%	
Building condition	Good or average	1,007	88%	90%		84%		93%	
Sidewalk presence in front of house	Yes	1,003	94%	96%		92%		96%	

Note. Building type, Building condition, and Sidewalk presence in front of house were reported by the interviewers.

^aThe percentage in each group = number of the target answers/number of effective answers.

^bSelf-rated health was measured by a single question “In general, would you say your health is excellent, very good, good, fair, or poor?”

^cThe building type question included three answers: one floor, multi-floor (two to six floors), and high rise (seven floors and above). Generally, the two- to six-floor residential buildings in Chengdu do not have elevators and those of more than six floors are required to have elevators by building code.

self-rated good, very good, or excellent health. However, this number was 53% for older people, while it was 73% and 91% for middle-aged and young people, respectively. In the sample, 64% lived in multi-floor buildings and the others lived in either one-floor houses or high-rise buildings; 88% lived in buildings of good or average condition while the others lived in dwellings in bad condition; and 94% had sidewalk in front of their dwellings. These numbers did not vary greatly among age groups. Notably, adults aged 60–70, and likely to be retirees, reported more exercise hours per week than younger ones, perhaps due to a more flexible schedule and awareness of health problems. A review by Li (2016) reports similar findings in studies in Shanghai and Guangdong Province though not elsewhere. Although the type of exercise was not recorded, other studies in China have found walking to be the most popular activity in this cohort (more than 90%; Li, 2016).

Statistical Methods

To compare the relationships of self-rated health with the built environment among different age groups, the study used a Bayesian logistic mixed-effects model in the statistical software *R* to regress health status on environmental variables for three age groups (young: <40 years, middle-aged: ≥40 years and <60 years, older: ≥60 years), while controlling for various sociodemographic and health-related behavioral confounders. Considering the association between self-rated health and the predictor variables may depend on which age-group the subjects belong to, interaction terms were included between age-group indicators and all other variables. The age-group terms comprised two binary indicators differentiating older people versus middle-aged people and older people versus young people. The remaining contrast, between middle-aged people and young people, was calculated from the model output. Including interactions in the model enabled us to estimate two quantities of interest: (1) estimates of the interaction effects indicated whether the association between health and a given predictor depended on age-group and (2) conditional estimates of the predictor variables for each age-

group revealed whether there was an association between health and a given predictor within this age-group.

Based on the sampling design, the model included two random effects, both grouped by PSU: Random intercepts were included to account for unexplained between cluster variability in the observations across PSUs, while random slopes for education (measured by year) accounted for heterogeneity in the relationship between health and education across PSUs. Conceptually, random slopes are used to account for the fact that the relationship between the response variable (health) and a Level 1 predictor (e.g., education) might differ across the levels of a Level 2 variable (e.g., PSU) due to unmeasured contextual factors. In this case, after exploratory visualization of several predictors against the health outcome while stratifying by PSU, it was determined that adding a random slope for education might improve model fit and this was confirmed by the model output.

A sensitivity check was performed to determine whether those individuals who exhibited nonresponse differed systematically from those who responded in full since the raw data included some missing values (approximately 3.5%) due to nonresponse to some survey questions. A binary indicator for whether a subject had missing values for any variable was created and then regressed against various demographic predictors, using a Bayesian logistic mixed-effects model with random intercepts grouped by PSU. Individuals with missing values tended to be significantly older and more educated than those with complete values. This sensitivity analysis indicated that simply removing individuals with missing values (i.e., list-wise deletion) would produce biased estimates from the final model. Thus, the study proceeded to impute the missing values via multiple imputation analysis. The *mitml R* package (Grund et al., 2019) was used to estimate a Joint Imputation Model (JIM)—a type of multivariate mixed-effects model—that included all available variables (missing and complete). Using the JIM, 10 new data sets were imputed, each with different estimates for the missing values. All further analyses used these imputed data.

All models were fitted in a Bayesian framework, both to achieve convergence to stable estimates and for the intuitive interpretation of the 95% highest posterior density credible interval (CR), which signifies a 95% probability of the true population parameter being within the interval. Models were estimated in *R* Version 4.0.2 (R Core Team, 2018) using the *brms* (Bürkner, 2017) package as a front-end to the Stan language (Stan Development Team, 2018). Model goodness of fit was assessed using posterior predictive checks—a method that assesses the congruence of the observed data to multiple data sets simulated from the model. Details of the modeling approach are available in the Supplementary Material for research repeatability.

Results

Table 4 shows the results of the Bayesian logistic mixed-effects model with interactions between the age-group indicators and other variables. For the older age-group, those who lived in the multi-floor buildings were less likely to report good, very good, or excellent health compared to those who lived in other building types (odds ratio [OR] = 0.42; 95% CR = [0.20, 0.92]). On average, the odds of reporting good health among older people who lived in the multi-floor buildings was .42 times that of those who lived in other building types. Those having at least one household member who was a smoker were less likely to report good health (OR = 0.33; 95% CR = [0.14, 0.80]). One hour's increase in exercise time per week was associated with 6% higher odds of reporting good, very good, or excellent health (OR = 1.06; 95% CR = [1.01, 1.11]). One more year of education was associated with an increase by 14% of the odds of reporting good, very good, or excellent health (OR = 1.14; 95% CR = [1.03, 1.27]). The associations of self-rated health with housing types and household smokers were significantly different between middle-aged and older groups.

However, fewer significant associations between self-rated health and other variables were identified among middle-aged and young groups. For the middle-aged group, on average, being 1 year older was associated with an 8%

decrease of odds of reporting self-rated good, very good, or excellent health (OR = 0.92; 95% CR = [0.87, 0.97]). Having 1 more year of education was associated with a 27% increase in odds of reporting good, very good, or excellent health on average (OR = 1.27; 95% CR = [1.15, 1.41]). Building condition and presence of a sidewalk were not associated with odds of reporting good, very good, or excellent health. Meanwhile, for the younger group, results showed no significant association of self-rated health with the studied variables.

Discussion

Built Environment Variables

In this study, older people had more problems associated with their self-rated health status than middle-aged and young people regarding the building-scale built environment and other factors. For older people, building type was associated with self-rated health status, while controlling for other factors including building condition and sidewalk presence in the model. Compared with those in single-floor buildings, and in high-rise elevator buildings, older people living in multi-floor buildings were less likely to report good, very good, and excellent health.

Multi-floor residential buildings usually do not have elevators in Chengdu, China. This survey was conducted in 2016, but as mentioned before, older communities in Chengdu only started retrofitting elevators in late 2018. The analysis showed that multi-floor walk-up buildings were a significant indicator of worse health status among the older group. They may influence older people's health by curtailing their outdoor activities such as exercise, daily errands, and social activities. Stair-climbing can be a big challenge for older people, while it is often not a problem for people younger than 60 and could provide health benefits due to increased exercise using stairs. The study indicated a significant difference in the association of self-rated health with housing type between the middle-aged and the older groups. In the older group, on average, the odds of reporting good, very good, or excellent health of those living in multi-floor buildings were only .42 times of that of those living in

Table 4. Results of the Bayesian Logistic Mixed-Effects Model for Self-Rated Health With Interaction Terms Between the Age-Group Variables and all Other Variables.

Key	Older Group Conditional Effect		Middle-Aged Group Conditional Effect		Young Group Conditional Effect	
	Odds Ratio	95% CR	Odds Ratio	95% CR	Odds Ratio	95% CR
Conditional estimates of indicator variables for each group						
Age	0.94	[0.85, 1.04]	0.92	[0.87, 0.97]	0.99	[0.92, 1.06]
Female	0.94	[0.39, 2.29]	1.41	[0.61, 3.19]	0.48	[0.17, 1.34]
Education (year)	1.14	[1.03, 1.27]	1.27	[1.15, 1.41]	1.11	[0.95, 1.29]
Smoking	0.98	[0.31, 3.13]	1.19	[0.45, 3.18]	1.57	[0.49, 5.20]
Exercise (hours per week)	1.06	[1.01, 1.11]	1.01	[0.97, 1.04]	1.01	[0.95, 1.06]
Having at least one household smoker	0.33	[0.14, 0.80]	1.09	[0.54, 2.31]	0.51	[0.21, 1.29]
Building type multi-floor	0.42	[0.20, 0.92]	1.25	[0.66, 2.44]	0.82	[0.32, 2.13]
Building condition good or average	0.84	[0.21, 3.55]	0.73	[0.32, 1.62]	0.91	[0.21, 3.65]
Sidewalk presence in front of homes	1.15	[0.18, 7.02]	0.88	[0.28, 2.70]	3.19	[0.58, 18.26]
Interaction variables (indicates how effects differ between age groups)						
Female: middle-aged group (indicates how the effects of gender on self-rated health differ between the middle-aged group and the other groups. Similar below)	1.50	[0.44, 5.01]			2.95	[0.80, 11.23]
Female: Older group			0.67	[0.20, 2.26]	1.97	[0.51, 7.76]
Female: Young group	0.51	[0.13, 1.93]	0.34	[0.09, 1.29]		
Education: Middle-aged group	1.11	[0.98, 1.26]			1.15	[0.98, 1.34]
Education: Older group			0.90	[0.79, 1.02]	1.03	[0.87, 1.22]
Education: Young group	0.97	[0.82, 1.15]	0.87	[0.74, 1.02]		
Smoke: Middle-aged group	1.22	[0.26, 5.30]			0.75	[0.17, 3.60]
Smoke: Older group			0.83	[0.18, 3.78]	0.62	[0.12, 3.30]
Smoke: Young group	1.62	[0.31, 8.42]	1.33	[0.29, 6.10]		
Exercise: Middle-aged group	0.95	[0.89, 1.01]			1.00	[0.94, 1.07]
Exercise: Older group			1.05	[0.99, 1.12]	1.06	[0.98, 1.13]
Exercise: Young group	0.95	[0.88, 1.02]	1.00	[0.94, 1.07]		
Having at least one household smoker: Middle-aged group	3.27	[1.04, 10.23]			2.15	[0.67, 6.81]
Having at least one household smoker: Older group			0.30	[0.10, 0.97]	0.65	[0.18, 2.32]
Having at least one household smoker: Young group	1.52	[0.43, 5.40]	0.47	[0.15, 1.54]		
Building type multi-floor: Middle-aged group	2.98	[1.16, 7.72]			1.53	[0.54, 4.29]
Building type multi-floor: Older group			0.34	[0.13, 0.86]	0.51	[0.16, 1.62]
Building type multi-floor: Young group	1.96	[0.62, 6.19]	0.66	[0.23, 1.92]		
Building condition good or average: Middle-aged group	0.88	[0.17, 4.49]			0.80	[0.16, 4.00]
Building condition good or average: Older group			1.11	[0.22, 5.72]	0.91	[0.13, 6.93]
Building condition good or average: Young group	1.11	[0.15, 7.93]	1.26	[0.26, 6.34]		
Sidewalk presence in front of homes: Middle-aged group	0.77	[0.10, 5.54]			0.28	[0.05, 1.80]

(continued)

Table 4. (continued)

Key	Older Group Conditional Effect		Middle-Aged Group Conditional Effect		Young Group Conditional Effect	
	Odds Ratio	95% CR	Odds Ratio	95% CR	Odds Ratio	95% CR
Sidewalk presence in front of homes: Older group			1.29	[0.18, 10.29]	0.36	[0.04, 3.78]
Sidewalk presence in front of homes: Young group	2.86	[0.28, 27.39]	3.71	[0.62, 22.73]		

Note. $N = 1,019$. Outcome variable: self-rated health (1 = good, very good, or excellent). The estimate is statistically significant (boldfaced text) if the value 1 is not contained within the 95% credible interval. CR = credible interval.

one-floor buildings and high-rise buildings equipped with elevators by building code. This relationship of self-rated health with building type was not significant among both middle-aged and younger groups.

The large number of multi-floor walk-up residential buildings in China might then be a serious problem due to the negative effects on older people's health. However, with few exceptions, research has rarely explored this problem. As mentioned earlier, using Fitbit tracking methods, Yu et al. (2020) identified that living on higher floors in walk-up buildings was associated with substantially lower odds of going outdoors among retired senior participants. The results of this study are consistent, finding that living in multi-floor buildings was associated with lower odds of reporting good, very good, or excellent health. This implies that upgrading the multi-floor buildings to have an elevator could improve older people's health.

Building condition was not significantly related to health. As mentioned previously, based on a systematic review, Thomson et al. (2013) concluded that, in terms of enhancing housing conditions for health, improving thermal comfort at home can benefit health. However, thermal comfort is not a serious problem in Chengdu due to its mild climate. Similar to the results in this study, Egan et al. (2015) interviewed 23 households in disadvantaged neighborhoods in Glasgow, UK, to examine residents' experience following relocation regarding health and environmental improvement, where some residents

reported improvement in health after they moved to homes in better condition, while others did not perceive any health improvement. Nevertheless, as mentioned previously, the building condition variable in this study was the interviewer's subjective evaluation of the overall condition. Further study may measure specific aspects of building conditions to explore this issue in more depth.

Furthermore, sidewalk presence in front of the home was not correlated to self-rated health in this study. Reviews have indicated that presence of sidewalks was related to more physical activities and better health outcomes (Choi et al., 2017; Feng et al., 2010). Recent studies have shown that problems with sidewalks in the neighborhood reduced the frequency of older people going into the neighborhood (Twardzik et al., 2020). However, sidewalk presence in front of one's dwelling, rather than the sidewalks presence and conditions in the wider neighborhood, may not be sufficient to promote physical activity and better health. In addition, it may have been that there was not enough variation in both the building condition and sidewalks variables in the survey, especially for the sidewalk variable, given 88% of buildings were of good or average condition and 94% of dwellings had sidewalks adjacent.

Social and Behavioral Variables

This study also found that the household environment and healthier behavior made a significant

difference in older people's self-rated health status. These correlations were not significant among young and middle-aged people. For the older group, more exercise hours per week was significantly related to better self-rated health. Moreover, passive smoking was another problem that negatively affected older people's health. The relationship of self-rated health with having a household smoker varied significantly among the middle-aged and the older group. Similarly, by analyzing data of 4,597 older people aged 60 and above in the years 2011 and 2013 from a Chinese national household survey on health, scholars also found that passive smoking at home was causing an increase in depression among older people (Lu & Wu, 2019).

Education was positively related to self-rated health among older and middle-aged people but not among young people in this study. The middle-aged (age 40–59) and older people (age 60–70) were born between 1956 and 1976 when China underwent significant disruption. Some of them received very little or no education (refer to Table 1), potentially limiting their ability to obtain knowledge and resources related to health. Meanwhile, younger generations were generally better educated, so education could have relatively less effect on their health status. A policy supporting a healthier society could target older and middle-aged people and help them to receive health information and resources.

Moreover, age by year was associated with perceived health in the middle-aged group but not in the younger or older groups. This may be because the middle-aged group represented a wider age range from 40 to 59, while the older age-group only ranged from 60 to 70. The younger group generally had high perceived health. However, self-rated health status worsened noticeably with increased age when considering the whole sample. Table 3 shows that the percentage of reporting good, very good, or excellent health was 91%, 73%, and 53% in young, middle-aged, and older groups, respectively.

Finally, the relationship between gender and self-rated health was not significant. Scholars have recognized complex gender differences regarding self-rated health. For example, male

and female groups may face different health problems and understand their own health differently (Deeg & Bath, 2003). A recent longitudinal study found no gender difference in reported health except for the oldest cohort born in 1924 to 1933, based on a nationally representative sample of 6,782 people surveyed in 1999–2011 in the United States (Etherington, 2017). The current study shows that gender was not correlated with self-rated health for all three age groups, controlling the demographic, behavioral, and environmental factors. When considering gender differences, it is worth mentioning that smoking is less prevalent among females than among males in China. For example, in our sample, 65% males smoked while this number was only 5% among females (refer to Supplementary Material Table S1). However, being a passive smoker in the household, women may suffer from the same health risks as the smokers do.

Limitations

There are several limitations to this study. First, although the sample was a probability sample from a survey conducted with rigid quality control, older and lower income people were over-represented compared to the population in the core city of Chengdu, probably because they were more likely to be at home and be interviewed. Moreover, the data did not indicate on which floor the participant was living, limiting some conclusions. For privacy reasons it is not known specifically where they were living within the PSU or half-square minute of latitude and longitude. Building condition was assessed by interviewer observation, which may have introduced error. Also, in this study, the building condition did not present much diversity, which may result in limited information for regression analysis. Furthermore, the income variable could not be used due to many missing values and, instead, education was used as a rough proxy of income level. Last, the sample included the youngest older people only, those aged 60–70. Further studies need to examine how the environment at the building scale can affect those older people above age 70.

Conclusion

A great number of studies have examined the relationships of health outcomes with the built environment at the neighborhood scale and also looking at the indoor environment. However, few studies have been done to investigate how health could relate to the building scale environment such as building types, building conditions, and the sidewalks in front of the dwellings connecting to the neighborhood. Further, research has rarely compared how these relationships differ among age groups in the same research settings. This article explored the relationships of self-rated health with built environment at the building scale and compared the differences among older, middle-aged, and young people while considering other factors including sociodemographics, healthy behavior, and household indoor environment. The study used a clustered random sample from a household survey on public health conducted in Chengdu, China, and analyzed it with a mixed-effects logistic model, which fully considered the hierarchical structure in the sampling process and modeled the interactions between age groups and other factors.

This study found significant differences existing in the relationships of self-rated health with some environmental and other indicators among age groups. For older people, living in multi-floor buildings and having a household smoker were associated with lower odds of reporting good, very good, or excellent health. The differences in these relationships were significant between middle-aged and older people. Moreover, longer weekly exercise hours were associated with higher odds of reporting good, very good, and excellent health for the older group. This relationship was not identified among middle-aged and younger people. Furthermore, having more education was associated with better self-rated health among older and middle-aged people but not significant in the young group. In addition, the percentage of reporting better health status dramatically decreased from the young group to the middle-aged group and to the older group.

This study provides evidence for urban policies and planning that target promoting health,

especially among older people, in the cities in less developed areas like Chengdu. Most importantly, policies should facilitate upgrading multi-floor walk-up buildings with elevators, which otherwise could be a significant health barrier to older people, especially in areas where older populations are concentrated. While the population is aging, the large number of these types of buildings could cause noticeable problems in public health in China and other places with similar dwelling types. New residential planning and design should be more aware that multi-floor walk-up buildings are not age-friendly and consider who the potential residents are in the longer term. Second, exercise and not having any household smoker are especially important to older people. City managers, urban designers, and healthcare providers could make more efforts to promote exercise of all kinds among older people, including providing outdoor facilities and home-based exercise programs, and also advertise and educate how passive smoking at home is harmful to older people. Additionally, public health education via all sorts of media, for example, TV and community service, could target older and middle-aged people and help them to obtain health-related knowledge, information, and resources.

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This article concludes that older people have more problems in the built environment and other aspects related to self-rated health compared to

middle-aged and young people. This highlights the importance of comparing age groups in the same research settings. This study contributes to the literature on environment and health by providing evidence on how building scale environment was associated with self-rated health. The findings provide implications for urban policy and planning that promote an age-friendly environment.

Implications for Practice

- To create a healthier environment for older people, provide residences with elevators when designing multi-floor residential buildings.
- Urban designers and planners can provide local environments, exercise venues, and facilities that support physical activity for older people. Healthcare practitioners should encourage older people to participate in outdoor and physical activities.
- Healthcare practitioners can communicate with older people's family members about the negative effects of passive smoking at home.
- Educating older and middle-aged people about health information and resources could have positive effects on health.

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Supplemental Material

The supplemental material for this article is available online.

Notes

1. The Hukou system is a residency registration regulation used as a method to manage population movement in China (Cheng & Selden, 1994).
2. In Chinese, “平房 [píng fāng]” means one-floor buildings. It often refers to the ordinary-looking one-floor buildings rather than expensive modern single-detached houses. In the core city of Chengdu, the examples of “平房” could be urban villages and preserved historical buildings. There is another Chinese word “别墅 [bié shù]” referring to expensive and modern single-detached houses.
3. It is possible that a very old walk-up building has seven floors or more; however, it is very uncommon in Chengdu.

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