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ARTICLE

Exploring the inner relationship among neighborhood environmental factors affecting quality of life of older adults based on SLR–ISM method

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Abstract
Neighborhood environment and indoor environment are two main living environments to older adults during their daily life. Until now, many researchers have already paid attention to the improvement in the indoor environment for older adults, but few researchers notice that neighborhood environment also plays a critical role in the quality of life (QoL) of older adults, especially older adults who are aging in place. This article aims to explore the complex inner relationship between neighborhood environment and QoL of older adults based on systematic literature review (SLR) and interpretative structural modeling (ISM). All neighborhood environmental factors related to QoL of older adults are searched, screened, quality assessed, counted, and then identified according to SLR protocol. Then, based on the questionnaire survey and the one-to-one interview, the ISM of all identified neighborhood environmental factors is established to clarify the inner relationship among those factors in urban areas, and the role of each neighborhood environmental factor is analyzed by MICMAC analysis. This inner relationship among neighborhood environmental factors can provide valuable retrofit strategies of neighborhood environment to improve QoL of older adults efficiently.

Keywords Neighborhood environment · Quality of life · Older adults · Inner relationship · SLR–ISM

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1 Introduction

Except for characteristics of an individual, living environment is regarded as a core aspect which closely related to residents' health and activities (Putrik et al. 2015). Due to the decline in physical function and mental health, older adults are more sensitive to their living environment compared with other residents (Clarke and Nieuwenhuijsen 2009). Nowadays, the population of older adults keeps increasing worldwide. According to the predication from United Nations, the worldwide proportion of people that are 65 or older will increase from 7.7% in 2010 to 15.6% in 2050, and the proportion in China will reach 23.6% (United Nations 2015). Consequently, China must face a huge challenge of providing an appropriate and suitable living environment for all older adults wherever they live.

In terms of aging theory, the place where older adults choose to age contains two main types: One is aging in the professional care institution and the other is aging in place, such as their own familiar community or housing (Golant 2015). However, because of the high expense in professional care institutions and the primary moral principles to take care of aging family members in China (Li et al. 2017), Chinese government started to pursue the community-based home-care service instead of institutional services to ensure that at least 97% of older adults can age in their homes and communities (Chen and Han 2016; Li et al. 2017). Therefore, the whole surrounding neighborhood environment becomes crucial to old adults. Because of that, the Chinese government started a project called "renew existed communities" nationwide in 2015 to improve the living environment of all residents living in old communities (Zhao et al. 2017).

The living environment is complex as it contains many elements, such as interior design, lighting, open space, and social network, and each element is possible to influence older adults. Loo et al. developed a graphical framework of a multi-scale environment based on different spatial scales of individuals (Fig. 1). The micro-level living environment is their own homes that individuals spend more time in it compared with another environment. The meso-level living environment is the neighborhood or community area that is within 10-min walk distance or 500 m around. The macro-level living environment is not

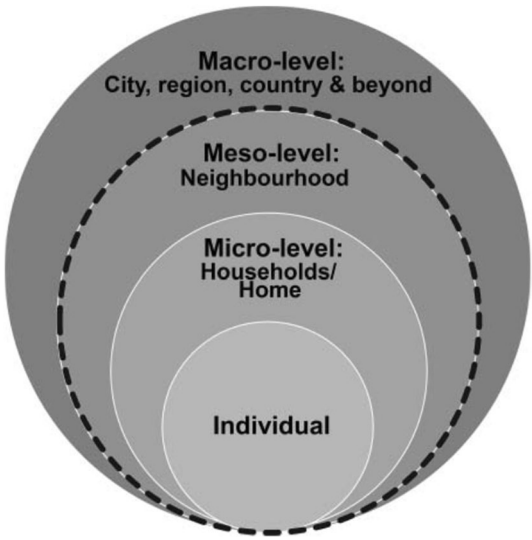

Fig. 1 Geographical framework of the multi-scale environment (Loo et al. 2017a)

the same for everyone as it depends on individuals' mobility (Loo et al. 2017a). Because of functional impairment and low mobility of older adults, most of their time is spent within micro- and meso-level living environments.

The meso-level living environment is also called neighborhood environment which is more complex for older adults in comparison with the micro-level living environment. Many researches have already been conducted to analyze the relationship between environments and older adults. For instance, World Health Organization (WHO) published a practical manual called "How to use the ICF: A practical manual for using the International Classification of Functioning, Disability and Health (ICF)" to explain the interactions between environments and old adults (WHO 2013). Components of neighborhood environments and their relationship with older adults have also been measured by researchers, such as the walkability and life quality of older adults (Loo et al. 2017b), accessibility and health of older adults (Granbom et al. 2016), sustainability of neighborhood environment and older adults (Jackie 2013), and social environment and physical activities of older adults (Chaudhury et al. 2012). However, there are rarely any researches that consider the neighborhood environment as a comprehensive system related to old adults and analyze the inner relationship of this system.

In this study, the quality of life (QoL) is chosen as the measurement of older adults' life instead of health, physical activities, or satisfaction. One of the most acceptable definitions of QoL is proposed by the World Health Organization Quality of Life Group (WHOQOL Group) as "individuals' perception of their position in life in the context of the culture and value system in which they live and in relation to their goals, expectation, standards, and concerns" (WHOQOL Group 1995). The QoL can cover core dominations of life assessment, such as physical health, psychogenic health, and social life. Therefore, the objectives of this study are to identify core neighborhood environmental factors affecting the QoL of older adults, to analyze the inner relationship among identified neighborhood environmental factors in the context of urbanization, and, finally, to provide helpful strategies to build a better neighborhood environment for improving the QoL of older adults.

2 Research methodology

This study combines the systematic literature review (SLR), which identifies core neighborhood environmental factors affecting QoL of older adults significantly, with the interpretative structural modeling (ISM), which analyzes the inner relationship among core neighborhood environmental factors.

2.1 SLR method

SLR is a method to scientifically summarize and synthesize the literature by avoiding errors of literature selection and subjective factors (Kitchenham and Charters 2007). In this study, the SLR method is adopted to fully identify and summarize all neighborhood environmental factors from previous related researches with a scientific, rigorous, and repeatable process.

There are several basic versions of SLR process, such as preferred reporting items for systematic reviews and meta-analyses (PRISMA) (Liberati et al. 2009) and Cochrane handbook for systematic review (Higgins and Green 2011). The basic process of Cochrane review—"define–search–select–assess–analyze" is appropriate for identifying

neighborhood environmental factors. However, some details need to be modified in this study since Cochrane review is usually used in the medical field which cannot be applied in this study directly. According to a version of the modified Cochrane review raised by Ahrentzen and Tural (2015), the main modifications adopted in this study are emphasized as follows:

(1) qualitative and mixed-methods studies were also included in addition to the quantitative studies, primarily randomized trials, which are the main focus of Cochrane Reviews; (2) instead of evaluating the effectiveness of particular interventions or clinical trials, this review explored the current evidence regarding the effects of neighborhood environmental factors on QoL from environment-, elderly- and QoL-related fields; (3) instead of a statistical meta-analysis of existing research, a factor identification was presented for a more in-depth review of a small number of studies; and (4) in addition to providing a review of the existing evidence, this study also sought to define the knowledge gaps and future research directions.

2.1.1 Search protocol

To obtain complete and accurate literature, it is essential to choose suitable electronic databases and set up search keywords. In this study, four main electronic databases are chosen to be the sources of literature as follows:

(a) Web of Science Core Collection (WOBCC), providing all high-quality articles indexed in SSCI, SCI, and A&HCI;
(b) MEDLINE, the most authoritative database in medical and biological fields;
(c) ELSEVIER, one of the biggest publishers in the world and its online database providing more than 2,000 journals related to both technology and medicine;
(d) EBSCO, also one of the biggest databases including several sub-databases.

Based on the objective of this research, three sets of search keywords are determined, and these three sets of keywords are used during a search in the topic category covering title, abstract, and keywords.

(a) "Neighborhood environment," which contains all variations of community environment, neighborhood environment, residential environment, and living environment;
(b) "Elderly," which includes older adults, senior, elderly, and older people;
(c) "QoL," which includes quality of life, life quality, and life.

Besides, the article language is limited to English, and the publication time is set between 1994 and 2018 for obtaining the literature of recent 15 years. The articles that do not qualify for these restricted conditions will not be adopted in search results.

2.1.2 Screening protocol

The results obtained from the search process are not all focused on the neighborhood environment and older adults. Thus, the screening process is conducted to remove these irrelevant articles with six steps as follows:

(a) Duplicate elimination

One article might belong to multiple databases. For instance, the article published by ELSEVIER may be indexed by WOBCC. Thus, the duplicate elimination process is required to ensure that there are no duplicated copies in the results.

(b) Attributes screening

In this study, conference articles are not considered since the research might not be mature or complete. Review articles are also not considered since they usually summarize the previous studies. However, conference articles and review articles are not separate from research articles in the search results. Therefore, this step is required to remove all the conference articles and review articles.

(c) Title screening

Title screening is required to filter these articles that are obviously not focused on neighborhood environment by reading the title.

(d) Abstract screening

In order to check whether detailed objectives and conclusions of researches are related to our SLR, the next step is to obtain the research information from abstracts. The articles that do not mention the influence of neighborhood environment on older adults in the objectives and conclusions have to be deleted.

(e) Full-text screening

In order to ensure the usability of the articles that are eligible for the above screening steps, downloading and reading the full texts of the articles is a necessary step to pick out the articles which cannot provide detailed neighborhood environmental factors.

(f) Reference screening

The references of remaining articles and the review articles identified in step (b) attributions screening are good supplements to target any missing eligible articles. Thus, in this step, all references are collected and screened again from the first step of the screening protocol.

2.1.3 Quality assessment (QA) process

After the search process and screening process, the remaining articles are all previous researches conducted on particular neighborhood environmental factors of QoL of older adults. However, even though all these articles were already published in peer-reviewed journals with a certain authority, the quality of articles is diverse. To select high-quality researches as final objects of the SLR, the quality assessment criteria proposed by Annear et al. (2014) are adopted in this SLR (Table 1). According to the contents of the articles,

Table 1 Quantitative and qualitative assessment parameters (Annear et al. 2014)

Assessment parameters	Assessment score			
	0	1	2	3
Quantitative				
Research design	NR/IN	Cross section/quasi-experimental design	Longitudinal	Randomized controlled trial
Reliability and validity of measures	NR/IN	Reliability and validity of some measures ascertained	NA	Pilot testing/prior verification of all measures
Sample size and representativeness	NR/IN	Small sample size	Sample size > 500 (power requirements not reported)	Representative sample (power requirements reported)
Response rate	NR/IN	< 60%	60–79%	≥ 80%
Appropriateness and statistical analysis	NR/IN	Generally appropriate, but some inconsistencies	NA	All hypotheses and objectives adequately addressed
Control of potential confounders	NR/IN	NA	NA	Potential confounders included in the analysis
Qualitative				
Research design	NR/IN	NA	NA	Appropriate to the aims of the study
Sampling and recruitment strategy	NR/IN	NA	NA	Appropriate to the aims of the study
Theoretical framework use	NR/IN	NA	NA	Theoretical framework for methods or design present
Evidence of reflexivity	NR/IN	NA	NA	Preconceptions or meta-positions are addressed
Rigor of data analysis	NR/IN	NA	NA	Well-documented and systematic process
Validation of findings	NR/IN	NA	NA	Triangulation and verification of results

NA not applicable, *NR* not reported, *IN* inappropriate in the context of the study

the assessment score can be determined objectively. The articles with a score lower than 9 will be removed from the SLR list.

2.1.4 Factor identification

Neighborhood environmental factors are collected directly from remaining articles after the QA process. It is easy to find three types of neighborhood environmental factors may exist in the process of the factor collection: (1) Some factors are considered as nonsignificant factors of QoL of older adults in some articles, while as significant factors in other articles; (2) the relationship of some factors with QoL of older adults is regarded as a significant factor by only a few articles; (3) some other factors affecting QoL of older adults significantly are supported by many articles. It is unreasonable to use all collected factors in the following analysis; thus, the further identification of factors is quite essential.

For picking out eligible and reliable factors, the frequency of these factors mentioned in remaining articles is chosen to apply in the factor identification. A neighborhood environmental factor with higher frequency indicates that this factor is quite important to QoL of older adults, since more researchers think it is worthy to be studied. A neighborhood environmental factor is regarded as both significant and nonsignificant factors of QoL of older adults, meaning that viewpoints on this factor are conflicting among different researchers. Only if majority articles support the significant influence of this factor on QoL of older adult, it can be recognized as a reliable factor affecting QoL of older adults significantly. Consequently, rules of factor identification are set as follows: (1) Only factors which be mentioned more than three times should be selected; otherwise, factors should be removed. (2) Check whether there are any selected factors with contradictory viewpoints. If any, only the factor with significant influence is supported by more than 80% of articles which mentioned it; this factor can be accepted; otherwise, this factor should be removed in factor identification.

2.2 ISM method

The neighborhood environmental factors were identified and collected based on the SLR. However, these factors are disordered, and their inner relationship is complex. Therefore, the ISM method was adopted to find the inner relationships and structures between the neighborhood environment and the QoL of older adults. Initially, ISM was a useful structural modeling method proposed by Warfield to analyze the complex socioeconomic system (Warfield 1973). Later, ISM was introduced into other field as a process to develop a map of the complex relationship between the elements involved in a complex situation.

The main function of ISM is transferring an unclear and complex system into a visible, ordered, and well-defined one based on researchers' and experts' knowledge and experience (Sage 1977). Generally, the ISM process consists of several steps as follows (Yang and Yang 2015):

Step 1 Formulate a structural self-interaction matrix (SSIM) of elements to display the pair-wise relationship between neighborhood environmental factors.
Step 2 Develop a reachability matrix from SSIM and check the matrix for transitivity.
Step 3 Partition the reachability matrix into different levels.
Step 4 Perform MICMAC analysis and directed graph to conceptualize the ISM.

3 Identification of neighborhood environmental factors: SLR

3.1 Results of searching, screening, and QA process

After the SLR analysis, 34 articles were kept. The detail results are given as follows:

In the search process, 328 articles were obtained from the four main electronic databases based on the keywords "neighborhood environment," "older adults," and "QoL." All articles were published between 1994 and 2018 in English.

In the screening process, 61 articles were removed in the duplicate elimination process. Sixteen conference papers and six review papers were removed in the attribute screening process. Forty-six articles were removed in the title screening process. One hundred and seven articles were eliminated in the abstract screening process. Fifty-three articles were removed from the list in the full-text screening process as no environmental factors were mentioned in these articles. Five articles were added to the reference screening process. After the screening process, 44 articles are eligible for the next QA process. In the QA process, ten articles were removed from the list as they are scored less than 9.

Finally, Fig. 2 shows the whole search and screening process with the detail number of articles picked out in each step. And Table 2 lists all the initial factors related to QoL of older adults which are summarized from the conclusion of articles directly. We can find that these initial factors belong to different aspects of neighborhood environment. For instance, the barrier-free design, street connectivity, sidewalk, and crosswalk describe the physical neighborhood environment; natural problem is natural neighborhood environment; the social cohesion, social network, and neighborhood support emphasize the social neighborhood environment; the public space, public transport, and accessibility of facilities describe the facilities or services within neighborhood environment; and crime and traffic are related to safety within neighborhood environment.

3.2 General characteristics of examined researches

Table 3 summarizes the general characteristics of above 34 qualified articles in terms of research location, research type, and research quality. In research locations, four continents are covered including Asia, Europe, North America, and South America. In South America, there is only one research conducted in Columbia. The other three continents are all popular research areas, and North America is the most popular one.

In research quality, most researches use quantitative methods to explore how neighborhood environmental factors influence the QoL of older adults, and only a few researches adopt the qualitative method. There are also two researches that combined quantitative method with qualitative one. Regression model and structural equation model are the leading quantitative methods to study the relationship in the 34 qualified articles. Although all the 34 qualified articles meet the QA requirements, they are not all in the same quality. One-fifth of the articles have the score of 14 or higher, and the rest are with lower scores.

3.3 Results of factor identification

However, not all the neighborhood environmental factors that are mentioned in the 34 qualified articles (given in Table 2) have significant effects on QoL of old adults. For instance, the positive effect of street intervention on QoL of old adults is not supported by strong evidence (Curl et al. 2015), and Vogt et al. considered no clear connection between green

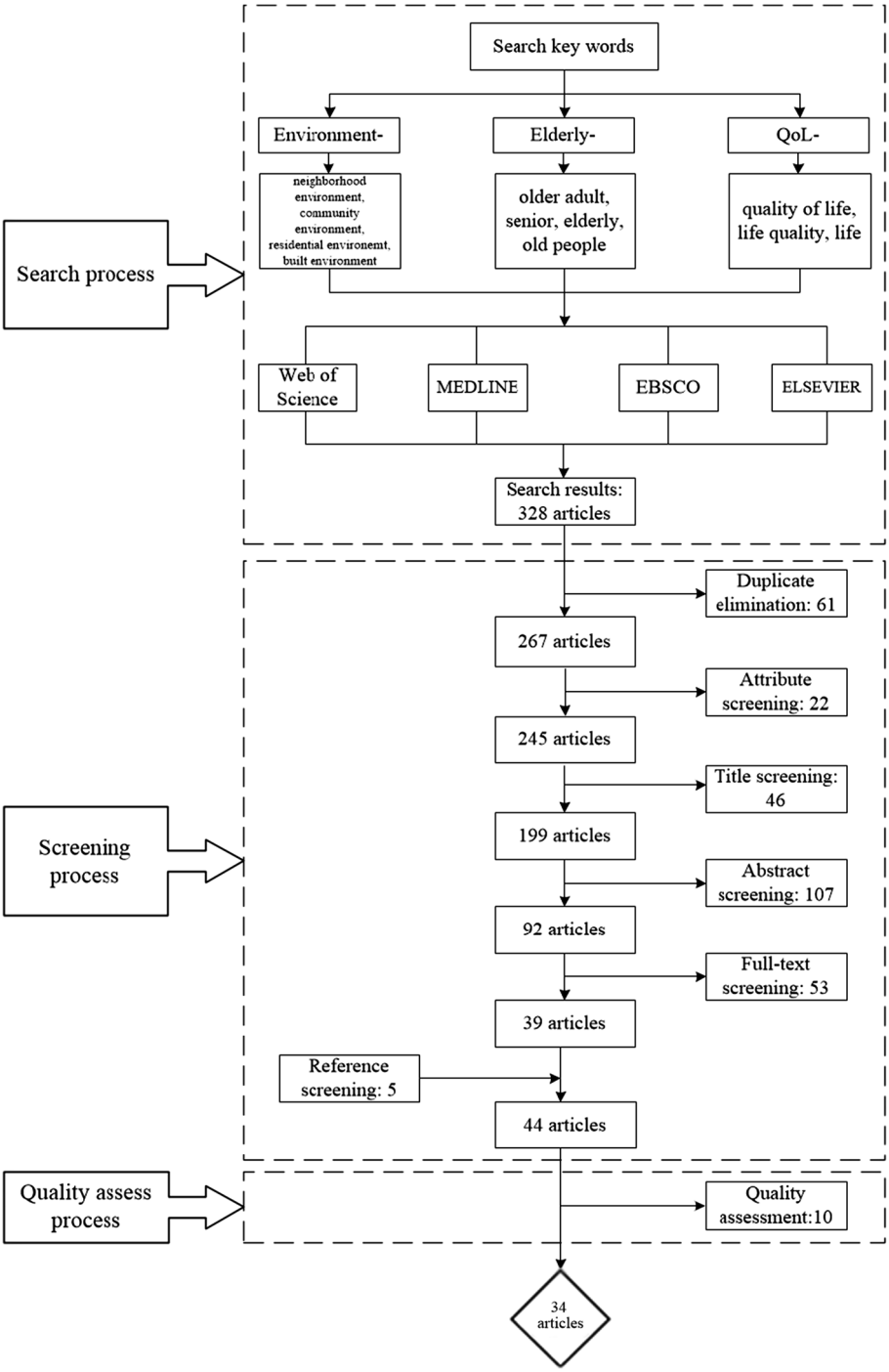

Fig. 2 Searching, screening, and QA process of the SLR

Table 2 Articles related to neighborhood environmental factors influencing QoL of older adults

Source (author, year)	Research area	Research type	Quality assessment score	Sample size	Initial neighborhood environmental factors
Cerin et al. (2014)	Hong Kong	QT	12	484	Access to shops, crowdedness, presence of sitting facilities, easy access of residential entrance, infrastructure of walking, access to public transport, land-use mix
Chaudhury et al. (2012)	Metro Vancouver, Metro Portland	QL	15	66	Safety and security, accessibility, comfort of movement, peer support
Chaudhury et al. (2016)	Metro Vancouver, Portland	QT	11	434	Parks, peer support
Chen et al. (2016)	Hong Kong	QT	9	400	Neighborhood support networks, perceived proximity by walk to community facilities
Clarke et al. (2015)	Chicago	QT	12	6518	Community resources, proximity to public transit, public spaces in good condition
Curl et al. (2015)	UK	QT	9	36	Street intervention (no significant)
Dujardin et al. (2014)	Belgium	QT	9	147,367	Built environment of a neighborhood (no significant)
Engel et al. (2016)	Metro Vancouver	QT	12	161	Street connectivity, social cohesion
Fernández-Carro et al. (2015)	European Union	QT	13	58,178	Access to service, environmental problem
Friedman et al. (2012)	New York City	QT	12	1870	Neighborhood safety (crime-related), social cohesion
Granbom et al. (2016)	Sweden	QT	10	1021	Irregular/uneven surface in exterior surroundings; high thresholds and/or steps at the entrance; stairs the only route (no lift/ramp) and storage areas can only be reached via steps or other difference in level
Hogan et al. (2016)	Berlin, Paris, London, New York, Toronto	QT	9	1638	Quality of services
Iwarsson et al. (2007)	Sweden	QT	14	397	Environmental barriers, accessibility problems
Levasseur et al. (2004)	Canada	QT	11	46	Social support
Lehning et al. (2015)	Detroit	QT	15	1376	Neighborhood problem (feel safe alone at day and night, count of neighborhood problems)

Table 2 (continued)

Source (author, year)	Research area	Research type	Quality assessment score	Sample size	Initial neighborhood environmental factors
Loo et al. (2017a)	Hong Kong, Singapore, Tokyo	MIX	12	607	Walkability, population density, quality of the sidewalk road surface, share of sociable seniors within the same community
Loukaitou-Sideris et al. (2016)	Los Angeles	QL	12	39	Good accessibility, age-friendly design and programming, opportunities for low-impact physical activities, environment supporting social interaction, attractive natural attributes, safe and secure environment
Koehn et al. (2016)	British Columbia	QL	15	42 (36 older adults and 6 staffs)	Security, control, accessibility, condition of sidewalks, placement of crosswalks.
Krause (1996)	USA	QT	15	1103	Social relationship, worst neighborhood environment (condition of yards and sidewalk, amount of noise, quality of air, etc.)
Mooney et al. (2017)	New York City	QT	12	3218	Proportion of residents living in extreme poverty, neighborhood socioeconomic status, and disorder
Parra et al. (2010)	Colombia	QT	12	1966	Safety from traffic, walking level, park being safety, street noise level
Rantakokko et al. (2015)	Jyväskylä, Muurame	QT	12	848	High curbs, safety of crossing roads, snow and ice, vehicles on the walkways
Ruengtam (2017)	Thailand	MIX	12	531	Activities and general facilities, facilities related to health and security, facilities related to physical exercise in residential communities
Sarkar et al. (2013)	UK	QT	12	684	Mix, density of retail, churches, recreational and leisure services, street network accessibility, slope variability

Table 2 (continued)

Source (author, year)	Research area	Research type	Quality assessment score	Sample size	Initial neighborhood environmental factors
Soma et al. (2017)	Kasama City	QT	12	509	Population density, land-use mix, number of daily life-related destinations, community centers, medical facilities, recreational facilities
Subramanian et al. (2006)	USA	QT	10	1926	Percent poverty, residential stability, concentration of elders
Vogt et al. (2015)	Augsburg	QT	12	1171	Distance to the nearest green space or senior center (no significant)
White et al. (2010)	USA	QT	11	436	Parks and walking area, handicap parking, public transportation
Wu et al. (2016)	Taiwan	QT	9	326	Environmental accessibility
Yan et al. (2014)	Beijing	QT	10	536	Outdoor space, elderly care facilities, medical facilities, barrier-free facilities, community services, service accessibility
Yoo and Kim (2017)	Seoul	QL	12	46	Design and crime-related safety, cleanliness, attractiveness, interestingness, accessibility of community resources, available public transit, green space
Yu et al. (2017)	China	QT	11	242	Barrier-free design
Zhang and Zhang (2017)	Cangzhou, Hejian, Huanghua Cities in China	QT	15	720	Security facility, shopping convenience, convenience of medical services, communal facility, activities center for aged people
Zhao and Chung (2017)	Hong Kong	QT	14	340	Aesthetic, physical barriers, crime

QT quantitative, *QL* qualitative, *REVIEW* literature review, *MIX* quantitative and qualitative

Table 3 Characteristics of examined researches

Categories	Types	Number of researches
Research type	QT	28
	QL	4
	MIX	2
Research location	Asia	11
	Europe	9
	North America	14
	South America	1
QA score	14–16	7
	12–14	13
	9–11	14

QT quantitative, *QL* qualitative, *MIX* quantitative and qualitative

space or senior center and the health aging (Vogt et al. 2015). Therefore, frequency statistics of initial neighborhood environmental factors (given in Table 2) needs to be conducted for further identification.

Table 4 shows the results of frequency statistics and explanation of each initial neighborhood environmental factors. In terms of the identification of standard mentioned in research methodology, 16 factors belonging to four main aspects are identified from the initial factor list—(1) physical and natural aspect: land-use mix (P1), barrier-free design (P5), street condition (P10), sidewalk condition (P13), natural environment (P16); (2) social aspect: peer/neighbor support (S2); (3) facilities/services aspect: accessibility of facilities/services (F1), public transport (F9), public space (F11), facilities/services related to health and security (F12), facilities/services related to physical exercise and recreation (F13), facilities/services related to daily life (F14); (4) physical safety and psychological security aspect: traffic-related safety (PS1), crime-related safety (PS2), design-related safety (PS3), security (SS5).

4 Inner relationship analysis: ISM

In order to explore the inner relationship among 16 identified neighborhood environmental factors (given in Table 5), ISM is used to establish this complex relationship model and transform it to a visual figure for future improvement in neighborhood environment. The complete ISM process includes data collection, model establishment, and MICMAC analysis.

4.1 Data information

The development of the ISM is mainly based on the experience and opinions of experts. For obtaining more complete and accurate inner relationship among neighborhood environmental factors, 46 experts' opinions about pair-wise influence relationships between any two neighborhood environmental factors were collected by the questionnaire survey through e-mail initially. Given that the situation of urban and rural areas is quite different, it is difficult to get exactly consistent expert opinions about inner relationship in

Table 4 Frequency statistic of neighborhood environmental factors

Aspect	Code	Neighborhood environmental factors	Explanation	Frequency of significant	Frequency of nonsignificant
Physical and Natural aspect	P1	Land-use mix	The diversity of land-use within neighborhood environment	3	0
	P2	Aesthetic	The degree of aesthetic of neighborhood environment	1	0
	P3	Walkability	The degree of friendly neighborhood environment is to walk for older adults	2	0
	P4	Infrastructure for walking	Infrastructures which help walking, e.g., blind tracts	1	0
	P5	Barrier-free design	The presence of the specific design for older adults within neighborhood environment	4	0
	P6	Residential entrance	The convenience to enter resident, e.g., life that can be used	2	0
	P7	Handicap parking	The particular parking space offered for the disabled	1	0
	P8	Stairs/lift/ramp to different level	The stair/life/ramp helping older adults move between different levels	1	0
	P9	Comfort of movement	The comfort level of older adults moving within neighborhood environment	1	0
	P10	Street condition	The general condition of streets in the community, including street network, street crowdedness, street intervention, street connectivity, the height of curbs, etc.	4	1
	P11	Street noise	The noise from streets	1	0
	P12	Placement of crosswalk	The suitability of crosswalk in the community	1	0
	P13	Sidewalk condition	The general condition of the sidewalk, such as road surface	3	0
	P14	Vehicles on the walkways	The vehicles driving or stopping on the walking ways	1	0
	P15	Slope variability	The variability of all slope in the community	1	0
	P16	Natural environment	The comfortableness of natural environment in the community, e.g., air quality and pollution	4	0

Table 4 (continued)

Aspect	Code	Neighborhood environmental factors	Explanation	Frequency of significant	Frequency of nonsignificant
Social aspect	S1	Social network	The social structure among individuals related to older adults	1	0
	S2	Peer/neighbor support	The help or support that older adults obtain from neighbors	4	0
	S3	Social cohesion	The extent of connectedness and solidarity among groups in society	2	0
	S4	Social relationship	A blanket term for interactions between two or more people, groups, or organizations in the community	2	0
	S5	Population density	The population density in the community	2	0
	S6	Concentration of elders	The degree of concentration of older adults in the community	2	0
	S7	Residential stability	The resident mobility within neighborhood environment	1	0
	S8	Neighborhood socioeconomic status	The economic and social position of neighborhoods	1	0
	S9	Percent poverty	What percentage of residents are poverty within neighborhood environment	2	0
Facility and service aspect	F1	Accessibility of facilities/services	How easily older adults access facilities/services	10	0
	F2	Attractiveness of facilities/services	How much facilities/services attract older adults to obtain	1	0
	F3	Cleanliness of facilities/services	How clean are facilities/services	1	0
	F4	Interestingness of facilities/services	How interesting are facilities/services	1	0
	F5	Proximity of facilities/services	The nearest distance from facilities/services to older adults	2	1
	F6	Quality of facilities/services	The quality of services in facilities	1	0
	F7	Density/number of facilities/services	How many facilities/services are located within a certain area	2	0
	F8	Opportunities for low-impact physical activities	The chance for older adults to do some low-impact physical activities, e.g., walking, cycling, yoga, etc.	1	0
	F9	Public transport	The presence of public transport within neighborhood environment	3	0
	F10	Parks	The presence of parks within neighborhood environment	2	0
	F11	Public spaces	The presence of public spaces outdoors within neighborhood environment, e.g., green space, yard, outdoor space, etc.	4	1

Table 4 (continued)

Aspect	Code	Neighborhood environmental factors	Explanation	Frequency of significant	Frequency of nonsignificant
	F12	Facilities/services related to health and security	Presence of facilities/services related to older adults' health and security within neighborhood environment, e.g., medical facilities, elderly care facilities, senior center, security facility, etc.	8	1
	F13	Facilities/services related to physical exercise and recreation	Presence of facilities/services related to older adults' physical exercise and recreation within neighborhood environment, e.g., recreational facilities, communal facility, activities center, sitting facilities, community centers, etc.	9	0
	F14	Facilities/services related to daily life	Presence of facilities/services related to older adults' daily life within neighborhood environment, e.g., retail, shops, churches, etc.	3	0
Safety and security aspect	SS1	Traffic-related safety	The unsafety caused by traffic	3	0
	SS2	Crime-related safety	The unsafety caused by crime	5	0
	SS3	Design-related safety	The unsafety caused by inappropriate design for older adults	3	0
	SS4	Facility safety	The unsafety during utilization of facilities/services	1	0
	SS5	Security	The environmental security older adults feel psychologically	3	0

Table 5 List of neighborhood environmental factors

Code	Factors	Code	Factors
1	Land-use mix	9	Public spaces
2	Barrier-free design	10	Facilities/services related to health and security
3	Street condition	11	Facilities/services related to physical exercise and recreation
4	Sidewalk condition	12	Facilities/services related to daily life
5	Natural environment	13	Traffic-related safety
6	Peer/neighbor support	14	Crime-related safety
7	Accessibility of facilities/services	15	Design-related safety
8	Public transport	16	Security

both urban and rural areas. Thus, experts were asked to provide their opinions under the context of urbanization. These experts include professors in related fields, government officials in *Bureau of Civil Affairs* and *Bureau of Housing and Urban–Rural Development,* leaders of non-governmental organizations (NGO) which provide services for older adults and the experts in real estate companies. The detailed information of these experts is given in Table 6.

According to the questionnaire survey, experts reach an agreement on majority of pair-wise relationships. However, experts' opinions on minority of pair-wise relationships between neighborhood environmental factors are conflicting. One-to-one interviews with experts are conduced to cope with this problem. Three types of experts are selected for one-to-one interviews: (1) experts who hold unique opinions; (2) experts whose opinions are supported by a few other experts; (3) one of experts whose opinions are similar to most experts. Finally, 12 experts are selected to be interviewed one to one for addressing contradictory opinions and ascertain exact inner relationship among neighborhood environmental factors. After two steps of questionnaire survey and one-to-one interview, all pair-wise relationships between any two neighborhood environmental factors can be confirmed.

Table 6 Description statistics of expert data

Category	Type	Percentage (%)
Age	Under 30	19.57
	30–40	34.78
	40–50	28.26
	Above 50	17.39
Occupation	University	39.13
	Government	17.39
	Non-governmental organization	23.91
	Real estate company	19.57
Region	Asia	58.70
	North America	21.74
	Oceania	6.52
	Europe	13.04

4.2 ISM establishment

4.2.1 Structural self-interaction matrix (SSIM) development

First, since pair-wise relationships among 16 identified factors are obtained from opinions of experts, the SSIM is developed by using four symbols to show these pair-wise relationships. Four symbols represent different relationships as follows:

V: Factor *i* influences factor *j*;
A: Factor *j* influences factor *i*;
X: Factors *i* and *j* influence each other;
O: Factors *i* and *j* have no relationship.

So, the SSIM of 16 neighborhood environmental factors is given in Table 7.

4.2.2 Reachability matrix formation

In this stage, the SSIM should be transferred to the initial reachability matrix by replacing the four symbols in Table 6 by 0 and 1. The particular rules of replacement are: If $D(i,j)$ of SSIM in Table 6 is shown with the symbol "V," $D(i,j)=1$ and $D(j,i)=0$ should be assigned in the initial reachability matrix; if $D(i,j)$ of SSIM in Table 6 is shown with the symbol "A," $D(i,j)=0$ and $D(j,i)=1$ should be assigned in the initial reachability matrix; if $D(i,j)$ of SSIM is shown with the symbol "X," $D(i,j)=1$ and $D(j,i)=1$ should be assigned in the initial reachability matrix; if $D(i,j)$ of SSIM is shown with the symbol "O," $D(i,j)=0$ and $D(j,i)=0$ should be assigned in the initial reachability matrix. Table 8 shows the initial

Table 7 SSIM of neighborhood environmental factors

Code(i, j)	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	O	O	O	O	V	V	V	V	V	V	O	O	O	V	O
2	V	V	O	O	O	O	O	O	O	V	O	O	V	V	
3	V	O	O	V	O	O	O	O	O	V	O	A	O		
4	V	V	O	O	O	O	O	O	O	V	O	A			
5	O	O	O	O	O	O	O	X	O	V	O				
6	V	V	V	O	O	A	O	A	O	O					
7	O	A	O	A	A	A	A	A	A						
8	O	O	O	V	O	O	O	O							
9	O	O	V	O	O	O	O								
10	V	O	V	O	O	O									
11	O	O	O	O	O										
12	O	O	O	O											
13	V	O	O												
14	V	O													
15	V														

V—factor i influences factor j; A—factor j influences factor i; X—factors i and j influence each other; O—factors i and j have no relationship

Table 8 Initial reachability matrix

Code(i, j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	0	1	0	0	0	1	1	1	1	1	1	0	0	0	0
2	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	1
3	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1
4	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1
5	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
9	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0
10	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1
11	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
15	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

reachability matrix obtained from the SSIM, showing all direct impacts among 16 neighborhood environmental factors. Then, the transitive links of initial reachability matrix are checked to find other indirect impacts. The final reachability matrix given in Table 9 is obtained by incorporating the transitivity.

4.2.3 Level partition

From the final reachability matrix, the reachability set which includes the factor itself and any other factor it influences, the antecedent set which includes the factor itself and any other factors which influence it, and the intersection set which includes factors in both reachability set and antecedent set can be found (Sage 1977; Warfield 1974). Table 10 summarizes the detailed reachability set, antecedent set, and intersection set of neighborhood environmental factors according to the final reachability matrix. All neighborhood environmental factors are divided into different levels. This level partition indicates the basic position of each neighborhood environmental factor in this complex relationship network. The factors that are in high levels, such as Levels 1 and 2, can be easily impacted by other factors, while the factors in low levels, such as Levels 4 and 5, are easier to influence other factors, and these factors provide the base in the whole relationship network.

4.2.4 Establishment of ISM

The results of processes above have already calculated inner relationship among neighborhood environmental factors. The ISM (Fig. 3) is established in terms of detailed inner relationships. All the neighborhood environmental factors are divided into five

Table 9 Final reachability matrix

Code(i, j)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Driving power
1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15
2	0	1	1	1	0	0	1	0	0	0	0	0	1	0	1	1	7
3	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	1	4
4	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1	4
5	0	0	1	1	1	1	1	0	1	0	0	0	1	1	1	1	10
6	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	1	5
7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1	4
9	0	0	1	1	1	1	1	0	1	0	0	0	1	1	1	1	10
10	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	1	4
11	0	0	0	0	0	1	1	0	0	0	1	0	0	1	1	1	6
12	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	2
13	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	3
14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	2
15	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	3
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependent power	1	1	5	5	3	5	14	2	3	2	2	2	7	7	8	14	

levels. The neighborhood environmental factors located in the higher level are influenced by other factors more, while factors located in the lower level influence other factors more.

4.3 MICMAC analysis

It is still difficult to obtain the characteristics of each factor directly from the ISM (Fig. 3) without further analysis of their driving power and dependence. The MICMAC analysis on ISM can address this limitation by classifying all the factors into four clusters. MICMAC is regarded as an effective method to explore the specific roles in the complex relationship with QoL of older adults.

The driving power and dependence of neighborhood environmental factors were already calculated in the final reachability matrix (given in Table 8). As shown in Fig. 4, the neighborhood environmental factors are presented in four quadrants. The function of the four quadrants is described as follows:

Quadrant I: Autonomous factors. Autonomous factors are with weak driving power and dependence. As shown in Fig. 4, public transport (code 8), facilities/services related to health and security (code 10), and facilities/services related to daily life (code 12) belong to this category; besides, street condition (code 3) and sidewalk condition (code 4) which are on the boundary between quadrants I and II are also regarded as autonomous factors.

Quadrant II: Dependent factors. Dependent factors are with high dependence but low driving power. Accessibility of facilities/services (code 7), traffic-related safety (code

Table 10 Level partition of factors

Code	Factors	Reachability set	Antecedent set	Intersection set	Level
1	Land-use mix	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16	1	1	5
2	Barrier-free design	2, 3, 4, 7, 13, 15, 16	2	2	4
3	Street condition	3, 7, 13, 16	1, 2, 3, 5, 9	3	3
4	Sidewalk condition	4, 7, 15, 16	1, 2, 4, 5, 9	4	3
5	Natural environment	3, 4, 5, 6, 7, 9, 13, 14, 15, 16	1, 5, 9	5, 9	4
6	Peer/neighbor support	6, 7, 13, 15, 16	1, 5, 6, 9, 11	6	3
7	Accessibility of facilities/services	7	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15	7	1
8	Public transport	7, 8, 13, 16	1, 8	8	3
9	Public spaces	3, 4, 5, 6, 7, 9, 13, 14, 15, 16	1, 5, 9	5, 9	4
10	Facilities/services related to health and security	7, 10, 14, 16	1, 10	10	3
11	Facilities/services related to physical exercise and recreation	6, 7, 11, 14, 15, 16	1, 11	11	4
12	Facilities/services related to daily life	7, 12	1, 12	12	2
13	Traffic-related safety	7, 13, 16	1, 2, 3, 5, 8, 9, 13	13	2
14	Crime-related safety	14, 16	1, 5, 6, 9, 10, 11, 14	14	2
15	Design-related safety	15, 16	1, 2, 4, 5, 6, 9, 11, 15	15	2
16	Security	16	1, 2, 3, 4, 5, 6, 8, 9, 10, 13, 14, 15, 16	16	1

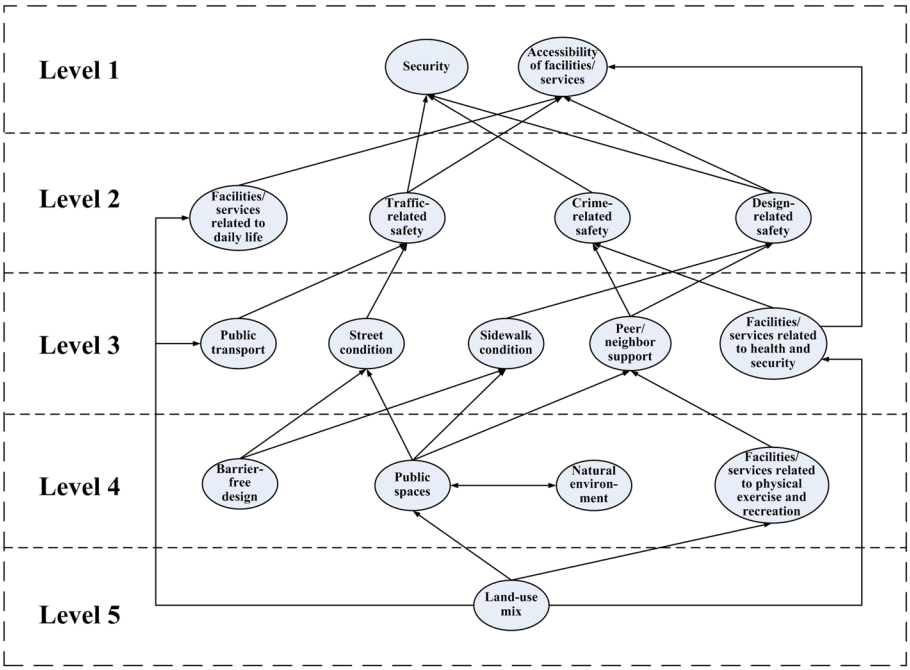

Fig. 3 Level partition and ISM of neighborhood environmental factors

13), crime-related safety (code 14), design-related safety (code 15), and security (code 16) are in quadrant II.

Quadrant III: Linkage factors. Linkage factors are with high dependence and driving power. The peer/neighbor support (code 6) is located on the junction point of four quadrants. Here, we consider it belonging to quadrant III.

Quadrant IV: Driving factors. Driving factors are with low dependence but high driving power. It is shown in Fig. 4 that land-use mix (code 1), barrier-free design (code 2), natural environment (code 5), public spaces (code 9), and facilities/services related to physical exercise and recreation (code 11) are in this quadrant.

In conclusion, the results of ISM present the complex relationship among neighborhood environmental factors, and MICMAC analysis divides these factors into four categories by driving power and dependence.

5 Discussion

The result of SLR identifies eligible neighborhood environmental factors, the result of ISM uses a structural model to present inner relationship among all identified factors, and the result of MICMAC analysis groups factors in terms of their attributes. Both ISM and MICMAC analysis show that 16 identified neighborhood environmental factors play quite different roles when influencing QoL of older adults. This offers valuable strategies for future optimization of the neighborhood environment.

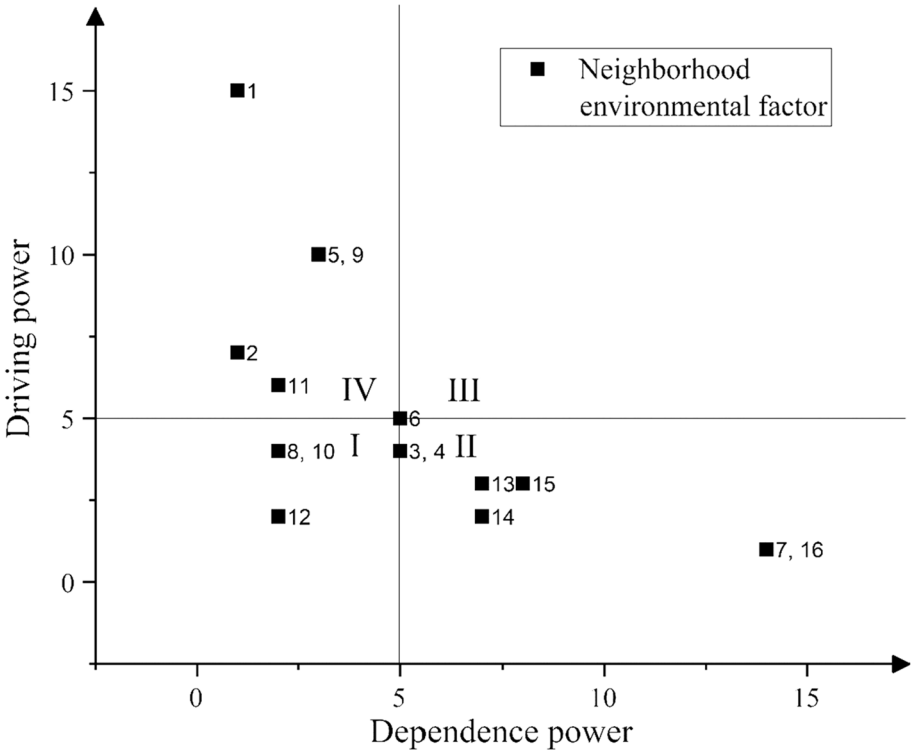

Fig. 4 MICMAC analysis of neighborhood environmental factors

Among all factors, the most fundamental factor is the land-use mix, which belongs to the driving factor. In the ISM graph (Fig. 3), the factor of the land-use mix is in the bottom, which provides fundament to almost else neighborhood environmental factors. Since the land-use mix is generally determined by government land-use planning (Wu et al. 2018), it is rarely affected by other neighborhood environmental factors. From the reachability matrix (Table 8), it is concluded that the land-use mix factor can influence seven neighborhood environmental factors directly. For instance, the land-use mix decides the present and location of facilities, as well as stations of public transport and public space within neighborhood environment. Besides, there are also eight other factors that have indirect relations with the land-use mix, for instance, the accessibility of facilities/services is affected by its present and location (Ingram 1971), which are decided by land-use mix, so the accessibility of facilities/services is influenced by land-use mix indirectly. Therefore, in order to improve QoL of older adults more efficiently, the government should pay more attention to the optimization of land-use mix with neighborhood environment at the very beginning and allocate more kinds of spaces, facilities, and public services located in the appropriate place for older adults.

In addition, barrier-free design, natural environment, public space, and facilities/services related to physical exercise and recreation also belong to driving factors. Similar to the land-use mix, the barrier-free design is usually decided by designers or planners, so it cannot be changed by neighborhood environment. But the barrier-free design can help

older adults avoid falling or other dangers and then improve the design-related safety when older adults move in communities (Yu et al. 2017; Parker et al. 2004). And a better barrier-free design also makes older adult access facilities more easily, enhancing the accessibility of facilities (Wennberg et al. 2010). Moreover, the natural environment and public space can only be affected by each other because the presence of public spaces like green spaces or yards can improve the natural environment to a certain degree. On the other hand, a good natural environment can lead to a high quality of public spaces. The natural environment and public space factors provide a firm basis for several other factors directly and indirectly. Regarding facilities/service related to physical exercise and recreation, it can provide a place for older adults to communicate with each other and strengthen friendship (Yu et al. 2017) and then enhance peer/neighbor support. Thus, these four factors should be enhanced before considering another parts of neighborhood environment.

On the contrary, the major characteristic of the dependence factors is that it can be easily influenced by other factors but only influence a few other factors. The accessibility of facilities/services and security are the most dependent factors which are located on the top of the ISM graph. As mentioned above, the accessibility of facilities/services always depends on locations of facilities and distances to facilities (Ingram 1971). Besides, street, sidewalk, design, and traffic within neighborhood environment are also closely related to accessibility, since older adults prefer walking rather than other transportation modes (Feng and Yang 2015). Similarly, the security of neighborhood environment is decided directly by the detailed design, safety, supports, and related facilities within the neighborhood environment and affected indirectly by other identified environmental factors (Chaudhury et al. 2012). Thus, even though the accessibility of facilities/services and security are quite important to QoL of older adults, they are hard to be improved directly.

It is shown in Fig. 4 that three factors of safety are dependence factors too, including traffic-, crime-, and design-related safety. But factors of safety have lower dependence power and higher driving power than factors of accessibility and security. Mainly because those three factors are determined by physical and social aspects of neighborhood environment and facilities, such as street condition, security facilities/services, and barrier-free design, they can also provide security for older adults.

Besides driving factors and dependence factors, the remaining five factors that are in the middle of ISM graph belong to autonomous factors, including street condition, sidewalk condition, public transport, and facilities/services related to health and security, and daily life. The links of autonomous factors with dependence and driving factors are not strong enough. That means the autonomous factors are only influenced by a few specific driving factors; meanwhile, they affect few specific dependence factors. This part of neighborhood environment should not be neglected for offering a pretty high QoL to older adults.

Particularly, the only one linkage factor is peer/neighbor support, which is located in level 3 in ISM graph. Peer/neighbor support usually contains all the formal and informal supports from the neighborhood (Chaudhury et al. 2012). The formal support refers to this unorganized help or communication within the neighborhood, for instance, the elderly's team of walking or running and the elderly's team of square dancing which organize formal activities every night. And the informal support means unscheduled help or communication with neighbors, such as hanging out with friends and meeting and talking with neighbors by chance. Both ISM graph and MICMAC analysis reveal that the neighborhood support links dependence factors and driving factors together. On the one hand, neighborhood support can be affected by public spaces and facilities related to physical exercise and recreation where older adults can enhance their friendship by communication; on the other hand, crime against older adults and injuries of older adults will be reduced if older adults

are in company with their neighbors, so neighborhood supports can also help to enhance the crime-related safety and design-related safety.

In summary, the land-use mix, barrier-free design, natural environment, public space, and facilities related to physical exercise and recreation are the most crucial neighborhood environmental factors influencing QoL of older adults. Only these driving factors are optimized at first; optimizing strategies on other parts of neighborhood environment can be effective. Besides, autonomous factors need to be considered and perfected as well, due to their impacts on accessibility, safety, and security of neighborhood environment. The only one linkage factor, the peer/neighbor support, should be encouraged for high-efficiency impacts of driving factors on dependence factors. At last, the accessibility, safety, and security will increase significantly after conducting the optimization strategies on driving and autonomous factors.

6 Conclusion

For detecting the inner relationship among neighborhood environmental factors related to QoL of older adults, this study is composed of two main parts. One part is identifying 16 key neighborhood environmental factors which affects QoL of older adults significantly based on the SLR method, and the other part is establishing the complex inner relationship among identified neighborhood environmental factors and detecting the function of neighborhood environmental factors in the improvement in QoL of older adults by using the ISM method. The process of this article is strict and accurate with the combination of SLR and ISM method. According to findings, even though all 16 neighborhood environmental factors have impacts on QoL of older adults, different factors play diverse roles in inner relationship within the neighborhood environment. Neighborhood environmental factors can be partitioned into four types: driving factors which affect other neighborhood environmental factors, including land-use mix, barrier-free design, natural environment, public spaces, and facilities/services related to physical exercise and recreation; dependent factors which are only influenced by other neighborhood environmental factors, including accessibility of facilities/services, traffic-related safety, crime-related safety, design-related safety, and security; linkage factors which not only affect other factors, but also are affected by another factors, including peer/neighbor support; autonomous factors which are independent of other neighborhood environment, including public transport, facilities/services related to health and security, facilities/services related to daily life, street condition, and sidewalk condition.

Findings of this study can provide valuable retrofit strategies of neighborhood environment to improve QoL of older adults efficiently. However, this study aims to propose a universal inner relationship among key factors of neighborhood and does not consider influences of locality differences on this inner relationship. In addition, this study does not propose a way to quantify this complex inner relationship among identified neighborhood environmental factors, since the ISM method cannot calculate the quantitative correlation coefficients among neighborhood environmental factors. Future studies will explore the inner relationship, in particular locations, compare its differences among different locations, and then propose a quantitative method to access inner relationship among neighborhood environmental factors affecting QoL of older adults in detail.

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