A Web-based Public Participation GIS for assessing the age-friendliness of cities: A case study in Tehran, Iran

Mohammadreza Jelokhani-Niaraki*, Fakhreddin Hajiloo, Najmeh Neysani Samany

Department of Remote Sensing and GIS, Faculty of Geography, University of Tehran, Tehran, Iran

1. Introduction

Progressive rises in urban population accompanied by the aging of societies are two global trends in urban sectors, emerging more often than not in developing countries (Srichuae, Nitivattananon, & Perera, 2016). The rapid growth of the elderly population has become a prominent, sustainable, global, and social phenomenon (Sun, Chao, Woo, & Au, 2017). According to predictions made by the World Health Organization (WHO), the proportion of the world’s population over 60 years will increase from 841 million in 2013 to more than 2 billion in 2050, representing a near two-fold increase in the percentage of the elderly population worldwide from 11.7 in 2013 to 21.1 percent in 2050 (WHO, 2015). It is also worth noting that the growth in the elderly population is expediting at a much faster rate than any other age group (WHO, 2015, Wong, Szeto, Yang, Li, & Wong, 2018). Nowadays, numerous senior citizens spend a substantial amount of their time in streets, parks, stores, and pedestrian sidewalks throughout cities. Consequently, ageing-related requirements and preferences should be taken into account in urban planning processes. Given the physical and psychological states of the elderly as well as their functional limitations, it is of utmost importance that certain proceedings be taken to provide a safe and healthy environment, augmented with other suitable forms of urban services to facilitate the mobility and social interactions of this target population (Guo, Matousek, Sonn, Sundh, & Steen, 2000; Esther, Winky, & Edwin, 2017). Social activities and interactions among the elderly are highly affected by the overall layout and the different features of their urban neighbourhoods and living environment (Borst, Miedema, de Vries, Graham, & van Dongen, 2008; Mohammad & Abbas, 2012). It is, therefore, imperative to pay attention to the living environment and urban neighbourhoods of the elder population so as to encourage a sense of satisfaction among the elderly (Temelová & Dvoráková, 2012; Temelová & Slezáková, 2014). An exact and strategic plan is thus needed to elevate the age-friendliness of cities and ensure quality of life as people age (Srichuae et al., 2016).

Urban neighbourhoods yield different levels of age-friendliness for the elderly based on the availability of services and facilities (e.g., transportation and health services), extant environment, social participation, housing density, etc. (Yan, Gao, & Lyon, 2014). Assessment and supervision of age-friendliness is a prerequisite for fabricating age-friendly environments (Buckner et al., 2017). Moreover, improvements in the age-friendliness of cities require exact and proper evaluation of the municipal services and the facilities provided to the elderly, owing to the fact that these evaluations form the groundwork for creating an age-friendly urban environment (Ruzza, Kim, Leung, Kam, & Ng, 2015; Steels, 2015; WHO, 2015; Buckner et al., 2017). Buckner et al. (2017) argue that increasing interest in the age-friendliness of cities and
communities in recent years has been accompanied by a growing number of frameworks of assessment and monitoring, and numerous frameworks for assessing and enhancing the age-friendliness of urban settings (see Buckner et al., 2017). For example, based on a research protocol implemented in 33 cities across all developed and developing countries, WHO developed “Global age-friendly cities: a guide” (WHO, 2007) and “Measuring the age-friendliness of cities: A guide to using core indicators” (WHO, 2015) as frameworks for the provision of structured guidance on selecting relevant and appropriate indicators of age-friendliness of a city. The set of indicators can be used to measure the level of age-friendliness of the city and monitor its changes over time as relevant interventions are implemented (WHO, 2007, 2015).

In addition to WHO resources, other frameworks and guides have been employed to assess the age-friendliness of cities (e.g., Phillipson, 2011; Phillipson, White, Aftab, & Hammond, 2013; Handler, 2014; Public Health Agency of Canada, 2015; Ruza et al., 2015; Steels, 2015; Wong, Chau, Cheung, Phillips, & Woo, 2015; Orpana, Chawla, Gallagher, & Escaravage, 2016). For example, a comprehensive age-friendliness guide called the “Age-friendly communities evaluation guide using indicators to measure progress” was developed based on the WHO guideline and tailored to meet the needs of Canadian communities through extensive consultations with stakeholders across Canada (Public Health Agency of Canada, 2015). Similarly, a research and evaluation framework for age-friendly cities has been produced by the UK Urban Ageing Consortium (Handler, 2014). Some of the guides and frameworks focus on measuring and assessing a particular dimension of age-friendliness such as health equity. For instance, an approach to assessing and responding to health equity in urban environments, focusing on the social determinants of health, is described in the Urban Health Equity Assessment and Response Tool (Urban HEART). The methods used in Urban HEART can be potentially adopted to address the notion of equity in age-friendliness (The WHO Centre for Health Development, 2016; WHO, 2015).

However, the larger part of age-friendliness studies and frameworks are primarily focused on developing indicators for evaluating and measuring age-friendliness of communities, rather than measuring and combining the indicators into a single index. The process of monitoring and evaluating the age-friendliness of a city demands practical tools and methods for measuring and integrating numerous influential indicators on the city age-friendliness. There are a few studies that describe the methods (e.g., conducting a survey, taking photos of outdoor spaces, accessibility checklists and using GIS analyses) used to measure and combine the indicators of age-friendliness (Cunningham, Michael, Farquhar, & Lapidus, 2005, Michael et al., 2009, Chaudhury et al., 2011, Shiau & Huang, 2014, Public Health Agency of Canada, 2015). For example, Shiau and Huang (2014) employed a questionnaire survey to analyze user perspective of age-friendly transportation. This study involved applying both qualitative and quantitative approaches to analyze users’ perspectives of age-friendly transportation. Environmental Audit Tool, a questionnaire-based method developed by the Centers for Disease Control and Prevention’s Healthy Aging Research Network (CDC-HAN), supports comprehensive assessment of neighbourhood walkability and community safety, with consideration of the needs of older adults and people with disabilities (Kealey et al., 2005). The Seniors Walking Environmental Assessment Tool (SWEAT-R) was developed (and recently revised to make it more brief) by Cunningham et al. (2005) to assess aspects of the built environment that affect older adults’ ability to participate in physical activities (see also Michael et al., 2009). It measures and scores different factors of buildings, sidewalks and buffer zones; personal and traffic safety; and aesthetics and destination, allowing one to calculate an overall “score of age-friendliness”. Neighbourhood Environment Walkability Scale (NEWS) is a questionnaire-based instrument that assesses the perception of neighbourhood design features related to physical activity, including residential density, land use mix, street connectivity, infrastructure for walking/cycling, neighbourhood aesthetics, traffic and crime safety, and neighbourhood satisfaction (Saelens, Sallis, Black, & Chen, 2003, Rosenberg et al., 2009). While not developed specifically for seniors, it is widely used and is considered to have excellent measurement properties. Given the vital role of accessibility in the age-friendliness of a community, several checklists have been developed and used to assess the accessibility of outdoor spaces and/or public buildings according to the needs of the elderly community.

Almost all of the mentioned methods for measuring age-friendliness are aspirational, failing to take notice of the geographical properties of age-friendliness measurement criteria. Put differently, they disregard the incorporation of spatial data and analyses in their assessment processes. One of the effective ways to evaluate age-friendliness of urban areas is the use of GIS-based methods. GIS is recognized as a powerful and integrated tool with unique capabilities for storing, manipulating, analyzing and visualizing spatial data for further planning and decision-making (Malczewski, 1999, Malczewski & Rinner, 2015). A large number of studies can be found which involve the use of GIS in urban life quality assessment (e.g., Elmahdi & Affify, 2007; Li & Weng, 2007; Rinner, 2007; Chen, Cerin, Stimson, & Lai, 2016; Murgaš & Klobučnik, 2016; Sessens, Khan, Huysmans, & Canters, 2017). Specifically, several studies have utilized GIS-based tools for planning age-friendly cities or evaluation of the city age-friendliness in terms of availability of urban services and facilities (Fadda, Cortés, Olivi, & Tovar, 2010; Somenahalli & Shipton, 2013; Verschuur, 2013; Koh, Leow, & Wong, 2015; Ruza et al., 2015; Bozdağ, Gümiş, Gümüş, & Durduran, 2017; Padeiro, 2018; Yang, 2018). An instance of this can be seen in the use of GIS techniques by Verschuur (2013) to analyze whether a city has the necessary services available or not and how well these services are accessible to the elderly population. Similarly, Ruza et al. (2015) developed a Web-based GIS to systematically evaluate the age-friendliness of Palo Alto, California based on the WHO guidelines.

The use of GIS tools for age-friendliness evaluation of cities comes with limitations. First of all, these tools have often been criticized for their limited ability to engage the elderly individuals and the inability to provide a platform for active participation and collaboration, due to their closed, synchronous and place-based nature (Boroughshki & Malczewski, 2010a; Jelokhani-Niaraki & Malczewski, 2015a, Jelokhani-Niaraki, 2018). According to Steels (2015) and Esther et al. (2017), one of the key factors in creating age-friendly cities and communities is the social participation of the elderly community. In other words, the diverse values, objectives, and interests of the older population form an integral part of the age-friendly community initiatives. The elderly’s concerns, preferences, ideas and opinions should be taken into account in the process of assessing and creating age-friendly cities. Elderly residents have in-depth knowledge and experience of their own living environment and could participate in the age-friendliness assessment procedure (Verma & Huttunen, 2015). This implies that assessment of the age-friendliness of a city should move from the traditional, centralized, expert-driven, and top-down approach to a more public, participatory, communicative, and elderly-driven practice. However, none of the GIS-based studies so far have provided a participatory and collaborative GIS-based approach to engage the elderly in assessing the age-friendliness of cities. Secondly, while the mainstream GIS technology could support the creation of easy-to-use, ubiquitous mapping and spatial analysis tools in the age-friendliness assessment process, it lacks the capability of collating and incorporating elderly’ interests and preferences in the assessment process. The information required for age-friendliness assessment cannot be captured by GIS alone, but entail specialized decision analysis procedures that go beyond the standard database manipulation and basic functions of GIS. It has been argued that the synergistic capabilities of GIS (GIS database and spatial analysis) and MCDA procedures (Multicriteria analytical models) can potentially enhance the participatory spatial assessment processes by providing a rich collection of techniques and procedures for eliciting the decision-makers’ preferences, structuring decision problems as well as designing, evaluating, and prioritizing alternative locations.
Finally, the age-friendliness maps produced by GIS analyses are somehow static and cannot easily change and adapt to the addition of new geographic information related to changes in the urban environment. While age-friendliness of an urban environment is highly context-dependent and a dynamic concept (WHO, 2015), it is not possible to monitor its changes through time using static maps.

The present study proposes a Web-based PPGIS (Public Participation Geographic Information System) for assessing and monitoring age-friendliness of cities. Specifically, it incorporates concepts of Volunteered Geographic Information (VGI), GIS, and Multicriteria Decision Analysis (MCDA) into the Web platform, which in turn provides an appropriate analytical tool for direct involvement of senior and regular citizens in the city age-friendliness assessment processes (see Boroushaki & Malczewski, 2010b; Meng & Malczewski, 2010; Gorsevski et al., 2013; Jelokhani-Niaraki & Malczewski, 2015a; Omidipoor, Jelokhani-Niaraki, Moeinmehr, Sadeghi-Niaraki, & Choi, 2019). It is participatory in the sense that: (i) the elderly people are able to specify their preferences relative to age-friendliness criteria/indicators; the collaboration of senior citizens representing diverse areas of experiences, political agendas, objectives and conflicting goals, scenarios, and social interests provide a synergic solution during the assessment process; (ii) regular citizens can contribute and generate geographical data, i.e., VGI about changes in urban areas, based on which the age-friendliness map is dynamically modified. The underlying idea behind integrating VGI and GIS-MCDA is that the VGI can complement GIS-MCDA tools during the age-friendliness assessment processes. While VGI can offer a potential solution for participatory, distributed, local and detailed collection of urban geographic data (Neis, 2015, Fatehian, Jelokhani-Niaraki, Kakroodi, Dero, & Samany, 2018), GIS-MCDA provides powerful tools with unique capabilities for storing, manipulating, analyzing and visualizing these data as well as a rich collection of procedures and algorithms for evaluating and prioritizing age-friendliness of urban areas.

2. Material and methods

2.1. Study area

The city of Tehran, Iran is currently experiencing a relatively high growth rate in its elderly population (Ahmadi, Seyedin, & Fadaye-Vatan, 2015; Mirzaie, Darabi, & Babapoor, 2017). As the largest city in the country, Tehran had a relatively low rate of population aged over 60 (320,430 individuals corresponding to 4.7% of the population) in 1996, a number which later increased to 464,638 in 2006 (Sharqi, Zarghami, Olfat, & Kousalar, 2016). Given the rapid decline in fertility and the increase in the number of elderly people in recent decades, future plans are needed to meet the recognized needs and preferences of the elderly community. District #6 of Tehran is selected as the study area (Fig. 1), due to the fact that it contributes to the largest elderly population among the 22 districts of Tehran (Municipality of Tehran, 2018b). According to existing statistics, the total population of the district is 251,384, among which 50,024 people form the over-60-years-old population (Municipality of Tehran, 2018a). District #6 is located at the center of the city and is considered as one of the relatively old regions of Tehran. Since the geographic data (the primary data) for the entire district was not available, only specific neighbourhoods of the district were selected. The neighbourhoods include University of Tehran, Valiaser-Englab Square, Iranshahr, Laleh Park, Behjatabad and Qam Maqm-Sanaye. The primary data was obtained from the maps previously generated by the municipality and other field observations and surveys.

2.2. PPGIS for assessing age-friendliness of cities

2.2.1. Conceptual framework

As shown in Fig. 2, the proposed PPGIS consists of four key components: people, VGI, GIS and MCDA. The people (users of the system) are classified into three groups: elderly citizens, regular citizens, and urban planners and managers. The elderly population is characterized by unique preferences with respect to the relative importance of criteria (i.e., weights), on the basis of which the age-friendliness of urban areas is evaluated. Each elderly citizen determines his/her preferences regarding criteria priority (pairwise comparison) based on the Best-Worst Method (BWM). Then the system automatically calculates the weight for each criterion as maintained by the elderly preferences. The weights obtained from the pairwise comparisons conducted by each elderly citizen are aggregated with the set of previously input weights using the geometric mean method; resulting in a single set of group weights. These weights can be used as input for generating the age-friendliness map.

In addition to the elderly, regular citizens could also contribute to the age-friendliness evaluation process by producing VGI data sets relevant to the criteria. The VGI data sets collected throughout the system can be used and analyzed by employing GIS-based functionalities to update the criteria map layers. In other words, the age-friendliness map is interactively updated in response to the addition of or changes in criterion weights by the elderly and addition/update/deletion of VGI by regular citizens. Finally, urban planners and managers can utilize the results of the system (the dynamic and up-to-date age-friendliness map) as a means for responding to the elderly’s needs, promoting their urban life quality, and decision making and planning in order to improve the urban environment for the elderly. To this end, the proposed system involves a four stage procedure for assessing the age-friendliness of urban environments: (i) determining the criteria weights using the BWM, (ii) aggregating the individual criteria weights into group weights, (iii) generating VGI-based criterion maps and (iv) integrating the criterion maps and group weights to generate the age-friendliness map.

2.2.1.1. Determining criterion weights. The elderly’s knowledge and preferences for assessing age-friendliness are expressed in terms of weights assigned to the evaluation criteria. For each elder citizen, weights of the age-friendliness criteria will be automatically calculated based on individual pairwise comparisons of criteria using the BWM. According to BWM, the best (i.e., most desirable, most important) and the worst (least important/desirable) criterion among the set of criteria are initially identified by the elderly population. Each of the two criteria (best and worst) are then compared with the remaining criteria (pair-wise comparisons). The final criterion weights are eventually determined by formulating and solving a maximization problem based on the pairwise comparisons. Rezaei (2015) argues that the noticeable features of BWM, compared to the existing MCDA methods such as Analytic Hierarchy Process (AHP) include: (1) significantly lower number of pairwise comparisons; (2) consistent comparisons and more reliable results. The BWM involves the following steps (see Rezaei, 2015):

a) Determining evaluation criteria

In this step, a set of age-friendliness criteria \{c_1, c_2, ..., c_n\} are identified as shown in Table 1. The resulting set of criteria should be complete, operational, decomposable, non-redundant, and minimal (Malczewski & Rinner, 2015).

b) Selecting best and worst criteria

This step involves identifying the Best (most important/desirable) and the worst (least important/desirable) criterion among the set of criteria. No pairwise comparison is made during this step.

c) Determining priority of the best criterion in relation to other criteria

In this step, a Best-to-Others vector is generated, indicating the
importance of the best criterion relative to the other criteria: 
\( A_B = (a_{B1}, a_{B2}, ..., a_{Bn}) \). The importance of the best criterion over the other criteria is specified using a value from 1 to 9. The value \( a_{Bj} \) shows the priority of the best criterion \( B \) in regard to criterion \( j \) (\( a_{B1} = 1 \)).

**d Determining priority of all criteria relative to the worst criterion**

Similar to the previous stage, priority is determined using a value from 1 to 9. The Others-to-Worst vector is defined as: 
\( A_W = (a_{W1}, a_{W2}, ..., a_{Wn}) \). The value of \( a_{Wj} \) shows the priority of criterion \( j \) over the worst criterion \( W \) (\( a_{W1} = 1 \)).

**e Finding the optimal weight**

The optimal weights of the criteria can be derived when the following conditions are met for each pair of \( w_B \) and \( w_W \):

\[
\frac{w_B}{w_W} = a_{Bj} \quad \text{and} \quad \frac{w_W}{w_W} = a_{Wj}
\]

In order to comply with these conditions, a solution should be found in which the maximum absolute difference \( \left| \frac{w_B}{w_W} - a_{Bj} \right| \) and \( \left| \frac{w_W}{w_W} - a_{Wj} \right| \) for all \( j \) is minimized. Considering that the weights are positive and their sum should total to 1, the following equation is derived.

\[
\begin{align*}
&\min \{ \max_j \left( \left| \frac{w_B}{w_W} - a_{Bj} \right|, \left| \frac{w_W}{w_W} - a_{Wj} \right| \right) \} \\
&\sum_j w_j = 1 \\
&w_j \geq 0 \text{ for all } j
\end{align*}
\]

This equation can be reformulated as:

\[
\begin{align*}
&\frac{w_B}{w_W} - a_{Bj} \leq \xi \text{ for all } j \\
&\frac{w_W}{w_W} - a_{Wj} \leq \xi \text{ for all } j \\
&\sum_j w_j = 1 \\
&w_j \geq 0 \text{ for all } j
\end{align*}
\]

The optimal weights \( (w_1^*, w_2^*, ..., w_n^*) \) and \( \xi^* \) can be obtained by
Table 1
The set of evaluation criteria for evaluating age-friendliness of city.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
<th>Criterion type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from health care and medical services</td>
<td>According to the WHO guide, access to health care and medical services including hospitals, clinics, pharmacies, emergency departments, etc. is one of the eight major indices of elderly friendly cities. Considering the elderly’s physical and mental health, access to these services is very crucial (Banister &amp; Bowling, 2004; Fitzpatrick, Powe, Cooper, Ives, &amp; Robbins, 2004; Somenahalli &amp; Shipton, 2013; WHO, 2015; Padeiro, 2018).</td>
<td>Minimum</td>
</tr>
<tr>
<td>Distance from public services</td>
<td>Due to physical conditions, the elderly have less access to urban public centers compared to other age groups. Expanding their access to services such as cultural-recreational centers, shopping centers, religious places and restrooms is a necessity for elderly friendly cities (Metz, 2000; Banister &amp; Bowling, 2004; Somenahalli &amp; Shipton, 2013; WHO, 2015; Supromin &amp; Choonhakhlai, 2017).</td>
<td>Minimum</td>
</tr>
<tr>
<td>Distance from public transportation</td>
<td>The elderly’s mobility requires special transportation services including bus stations, subways and taxis (Banister &amp; Bowling, 2004; Broome, Worrall, Fleming, &amp; Boldy, 2013; Shiu &amp; Huang, 2014; Murray, 2015; WHO, 2015; Srichuay et al., 2016; Wong, Saeto, Yang, Li, &amp; Wong, 2017). Public transport facilities should be physically accessible for the elderly, including those who have limitations in mobility, vision or hearing.</td>
<td>Minimum</td>
</tr>
<tr>
<td>Distance from green spaces</td>
<td>Access to elderly-friendly green spaces including urban parks and gardens is a common feature of age-friendly cities. Desirable access to green spaces has a positive impact on the elderly’s health (WHO, 2015; Arnberger et al., 2017; Artmann et al., 2017; Wen, Albert, &amp; Von Haaren, 2018).</td>
<td>Minimum</td>
</tr>
<tr>
<td>Neighbourhood walkability</td>
<td>Quality of pavements in regards to their width, flooring, cracks and unevenness, crowdedness, chairs, etc. is important for the elderly’s mobility in the city (Borst et al., 2008; Borst et al., 2009; Mitra, Siva, &amp; Kehler, 2015; WHO, 2015). Neighbourhood walkability focuses on quality of streets in the neighbourhoods; i.e., availability of pedestrian paths which meet locally accepted standards.</td>
<td>Maximum</td>
</tr>
<tr>
<td>Pollution</td>
<td>Environmental pollutions such as the air, noise, and disposal of wastes severely threaten the elderly’s health (Auger-Duplaix, Bilodeau-Bertrand, Lo, &amp; Smargiassi, 2018; Lepesle et al., 2018; Schnass et al., 2018; Yang et al., 2018).</td>
<td>Minimum</td>
</tr>
<tr>
<td>Safety</td>
<td>Sense of safety among the elderly is a necessity for age-friendly cities. The existence of facilities such as lights and police stations as well as low rates of accident and crimes committed against older people in the streets decrease the fear of moving outdoors. These are the main factors affecting the elderly’s safety (Corbi et al., 2012; WHO, 2015; Smolik &amp; Čeněk, 2017; Xu, Fu, Kennedy, Jiang, &amp; Owusu-Agyemang, 2018).</td>
<td>Maximum</td>
</tr>
</tbody>
</table>
solving the equations above (Rezaei, 2015).

2.2.1.2. Aggregation of criteria weights. Since participatory assessment of city age-friendliness involves the elderly population, with their accompanied conflicts in assigned weights and preferences (different interests, ideas, values, and opinions), the system ought to be able to integrate the sets of individual criterion weights into a single set of group weights (Boroushaki & Malczewski, 2010c, Gorsevski et al., 2013, Jelokhani-Niaraki & Malczewski, 2015c). To this end, the individual weights can be aggregated using either arithmetic or geometric mean. The geometric mean (Eq. (4)) has been used in this study owing to the fact that it is more suitable for aggregating weights obtained from the pairwise comparisons (Malczewski & Rinner, 2015).

\[ W_{ik} = \sqrt[n]{w_{ij}w_{ij}...w_{iu}} \]  

where \( w_{ik} \) is the weight of \( j \)-th criterion based on the opinion of \( k \)-th elderly citizen, \( u \) is the number of elderly citizens, and \( w_{ij} \) is the group weight of \( i \)-th criterion based on the preferences of the entire elderly population.

2.2.1.3. Generating VGI-based criterion maps. Map layers are a known format for storing and representing criteria values in a GIS database. Each of these layers shows the values assigned to every location (or cell-by-cell across the urban areas) with respect to a particular age-friendliness criterion. Maleczewski (1999) argues that the process of generating criterion maps is in accord with the main functions of GIS, where the relevant geographical data are acquired and stored in a GIS database and then analyzed to generate the criterion maps. Generally, geographic data used in the proposed system for generating age-friendliness criteria are classified into two sets: the primary geographic data (static data) and the VGI (dynamic data) relevant to urban areas. The primary data (authoritative data produced by government agencies) are collected a priori and are stored in the GIS database and then analyzed to generate the criterion maps. Generally, geographic data production by government agencies, citizens could also play a significant role in producing VGI of all kinds through a bottom-up crowdsourcing process (Sui, Goodchild, & Elwood, 2013; Jelokhani-Niaraki, Bastami Mofrad, Yazdanpanah Dero, Hajiloo, & Sadeghi-Niaraki, 2019). VGI is based on the concept that citizens act as a network of human sensors that aim to collect geographic information in a voluntary manner. This involves the widespread engagement of citizens, often without supervision and with very little training, in the generation of geographic information (Goodchild, 2007). Citizens can therefore serve as analytical, smart, responsible, context-aware, mobile, distributed and interactive sensors for monitoring urban environments and producing urban geographical data using technologies such as phones, tablets, computers, and other devices (Jelokhani-Niaraki, 2017, Jelokhani-Niaraki et al., 2019). Consequently, the VGI component of the system aids regular citizens in producing geographic data, which can be used for age-friendliness assessment. This component is designed to update the primary geographic data and add the new data into the system in accordance with changes observed in the city or urban environment. It allows the citizens to report changes in the location of urban facilities, health care and medical services, transportation stations, green spaces, purchasing and selling centers, etc. on the map. For example, regular citizens could report whether their neighbours are appropriate, or rather inappropriate for walking, especially for those who use wheelchairs and other mobility aids (WHO, 2015). Once new data is fed into the system, it is incorporated into the corresponding map layer.

In this study, the criterion maps were developed using Web-based GIS analytical functions based on both primary geographical data and VGI. GIS functions such as Euclidean Distance and Buffer analysis were used to generate different criterion maps such as noise, pavement state, safety, and light maps. The output criterion map layers were selected as the input data for the MCDA process. Since the MCDA aggregation decision rule requires that the criterion maps be commensurate, the criterion maps should be standardized prior to being used in GIS-MCDA. The standardization procedure involves normalizing the criterion maps (values) to comparable scales (values between 0 and 1).

2.2.1.4. Aggregation of criterion maps and weights. Finally, the group weights and the standardized criteria maps are combined using Weighted Linear Combination (WLC) method to obtain the overall age-friendliness scores for locations in the study area (i.e., age-friendliness map of the city). The overall score is determined by multiplying the group weight assigned to each criterion by the standardized value given to the location for that criterion, and ultimately summing the products over all criteria as follows:

\[ S_i = \sum_{j=1}^{n} a_{ij}w_{ij} \]  

where \( a_{ij} \) is the standardized value of \( i \)-th location with respect to \( j \)-th criterion.

Every time regular citizens produce new VGI of urban environments or a set of weights are added by a new elderly via the system, the GIS, standardization and WLC procedures can be reiterated to update and generate a new age-friendliness map of the city. Stated differently, the system dynamically and interactively assesses the elderly friendliness of the cities with respect to the changes in the elderly’s opinions, addition of new elderly’s opinion and introduction of new participatory geographic information related to changes in the urban environment.

2.2.1.5. Sensitivity analysis. Generally, there are uncertainties in criterion weights due to many different reasons such as the inability of the elderly people to provide precise judgments relative to the importance of age-friendliness assessment criteria. The elderly may be unable to accurately specify their preferences due to limited or imprecise information and knowledge. Sensitivity analysis is performed to examine how the uncertainty in the elderly’s preferences (weights) affect the decision outcomes (age-friendliness of the locations/ alternatives). The sensitivity of the overall score associated with an alternative location to the criterion weight variation is determined by considering a single weight at a specific time and changing its value from 0 to 1 (Malczewski & Rinner, 2015). Once the weight has changed, the overall score of the alternative location, \( S(A_i, w_t) \), can be calculated as follows (Chen, Wood, Linstead, & Maltby, 2011):

\[ S(A_i, w_t) = w_t S(a_t) + \sum_{k=1, k \neq t}^{n} w_k S(a_k) \]  

\[ w_{ik} = \frac{(1 - w_t)w_i}{\sum_{k \neq t} w_k} \]  

where \( w_t, w_{ik} \) and \( w_k \) are the weight of criterion \( k \), the adjusted weight of criterion \( k \) and the addressed weight, respectively; \( S(a_k) \) and \( S(a_t) \) are the values of alternative \( A_i \) with respect to the \( k \)-th and \( t \)-th criterion, respectively. A range of weight deviations are applied to each criterion weight, altering them by a small increment throughout this range. Upon updating the weight of the criterion to a new weight (addressed weight), the weights of other criteria are adjusted proportionately to satisfy the requirement that the sum of all weights be equal to 1.0 (adjusted weights).

2.2.1.6. Validation of age-friendliness map. The resulting age-friendliness map is compared with another age-friendliness map generated using Borda method based on the elderly’s subjective views. Borda is the most frequently used technique in GIS-MCDA for aggregating individual preferences (e.g., Jankowski, Zielinska, &
Swobodzinski, 2008; Gorsevski et al., 2013; Jelokhani-Niaraki & Malczewski, 2015a; Malczewski & Rinner, 2015). This approach has been employed to determine the group rankings of neighbourhoods /locations with regards to their age-friendliness based on the number of elderly people who prefer that specific neighbourhood over others. The use of the Borda method for ranking the neighbourhoods in the form of age-friendliness map involves three stages: (i) each elderly first ranks the age-friendliness of the six neighbourhoods based on his/her subjective view, (ii) pairwise comparisons are made among the ranks of neighbourhoods to derive individual points; for each pair of neighbourhoods, Ni and Np, Ni gets 1 point if it is preferred over Np (characterized with higher rank); and 0.5 if an elderly is, from the perspective of age-friendliness, indifferent towards the two neighbourhoods, and (iii) the Borda score is then determined for the i-th neighbourhood by summing the individual point values for that neighbourhood. The neighbourhood with the highest Borda score is considered as the most age-friendly neighbourhood.

2.2.2. Criteria and data sources

The set of criteria for evaluating age-friendliness of the city was developed through an examination of the relevant literature. The WHO guide (WHO, 2015) was used as the basis and most relevant source for developing the criteria for evaluating the age-friendliness of the city. This instruction provides a guideline to facilitate the selection of essential factors for establishing standards, setting goals/targets, and monitoring and evaluating age-friendly city initiatives. In principal, the WHO guide presents 8 different factors that can be considered by cities and communities in order to better adapt their structures and services to the needs of older citizens including: the built environment, transport, housing, social participation, respect and social inclusion, civic participation and employment, communication, community support and health services. However, criteria identification is a highly localized activity, conditioned to cultural and socio-political influences. While a set of criteria may be broadly accepted by all senior citizens in one city, the same set may be entirely unacceptable in another city. The WHO guide could be adapted to the local context (e.g., socio-cultural context, level of resources, needs and priorities, specific goals and interventions adopted by the city) in order to encourage local innovation (WHO, 2015). Thus in the second step, a survey of opinions was conducted to select the evaluation criteria based on the WHO guide. To this end, different meetings were held with 30 elderly citizens from different neighbourhoods (public parks) to discuss the criteria. Finally, a long list of criteria were obtained in regards to the elderly-friendliness of the city. Since the system evaluates elderly-friendliness using a participatory approach, wherein the participants include typical and ordinary elderly citizens, the use of a high number of criteria would complicate the evaluation process and avert from desirable outcomes. In order to overcome this problem, similar criteria were integrated and their number was kept as small as possible. The minimal set of criteria reduces the effort required for specifying the criteria weights by the elderly population. Ultimately, a total of seven criteria were selected (Table 1).

Primary geographical data required for developing the criteria maps was then procured. The geographic locations of urban services required for the elderly, such as health care and medical services, public transportation stations, parks and green spaces were obtained from municipal maps (www.map.tehran.ir). Given that the geographic data on pavements, street lights, crimes and neighbourhood pollution were not initially available, field surveys were conducted to collect the corresponding data. These data would be further updated by citizen-generated geographic information (i.e., VGI) via PPGIS.

2.2.3. System description

The proposed PPGIS was developed based on a client-server architecture (Fig. 3). The main motivation for the use of such an architecture in a PPGIS is the potential efficiency of information processing that can be recognized from distributing processing functions between client and server (Jankowski & Nyerges, 2001). The server contains a geographic database and the GIS server. The GIS server used in this system was the GeoServer. GeoServer is a Java-based open source software server which enables the users to share and edit geographic data. Using the OGC standards (www.opengeospatial.org), GeoServer has created a high level of flexibility in creating, publishing, sharing and analyzing the data represented by map services such as Web Feature Service (WFS) and Web Map Service (WMS). In accordance with the system architecture, PostgreSQL (PostGIS) was used as the geographic Database Management System (DBMS) to store primary geographic data and VGI. GeoServer allows the system to access, display, query and analyze geographic data provided by the services. This functionality enables the system to generate VGI-based criterion maps and the elderly-friendliness map of the city.

The user interfaces on the client side include registration, log-in, training, decision making, VGI input, and age-friendliness assessment Web pages. In order to design the client component, Web-based tools such as HTML (Hyper Text Markup Language), CSS (Cascading Style Sheets), and Javascript were employed. To publish the map services in the pages, open source libraries such as OpenLayers and JQuery were utilized. OpenLayers is a powerful open source JavaScript library which is used to demonstrate maps in Web pages. In the proposed system, the Google Maps service was deployed as the base map in order to draw the VGI and represent the elderly-friendliness of the city on the map. Google Maps provides some of the more straightforward capabilities of GIS which are accessible to the general public (Goodchild, 2007), where novice and lay citizens are able to read, write, alter, and represent the geographic data of urban changes in terms of points, lines and polygons on the map. Google Maps ease of use plays a key role in its success in the participatory age-friendliness assessment process due to the fact that even individuals who are not familiar with GIS capabilities could easily use it.

User registration is the first stage of the age-friendliness assessment procedure. Each elderly participant must complete and submit the registration form individually. Upon completing the registration form, users are redirected to the “Criteria comparison” page. In this page, a form composed of four parts is designed based on the BWM. This page allows the elderly to determine the criteria priorities (see Fig. 4). The elderly choose the most and the least important criterion among the seven criteria via the first and second parts of the system, respectively. The priority of the best criterion to the other criteria and the priority of all the criteria to the worst criterion are both determined as a number from 1 to 9 in the third and fourth parts, respectively.

The “VGI input” page provides map-based tools for regular citizens to produce the geographic information relevant to urban changes (see Fig. 5). Citizen-generated geographic data illustrate changes including the addition of new services or changes in the state of these services within the urban environment. For example, citizens may report any kind of change occurring in the locations of health care and medical facilities, public services, shopping centers, religious places, etc. In order to input information about the aforementioned items, citizens must first specify the type of the urban service (e.g., health care and medical facilities); then mark the corresponding location by different geometries (e.g., point, line, and polygon features) on Google Maps with a specific time and date.

Fig. 6 shows the resulting age-friendliness map of the city. The age-friendliness map is both dynamic and interactive. It is dynamic in the sense that it changes over time based on the changes in the elderly’s preferences or with the addition of new elderly’s preferences and new geographic information related to changes in the urban environment. The map is interactive in the sense that it is updated based on citizen and elderly inputs. It is interactively updated in response to addition of or changes in criterion weights by the elderly and addition/update/deletion of VGI by regular citizens. Each time a citizen enters a new piece of information in either the decision making or the VGI pages, the
A couple of GIS-MCDA studies put emphasis on interactivity for the purpose of simultaneous representation of multiple information pieces via the dynamic linkage between decision aids in an spatial decision making process (Jankowski, Andrienko, & Andrienko, 2001; Andrienko & Andrienko, 2002; Markieta & Rinner, 2014; Malczewski & Rinner, 2015). Particular attention is paid to dynamic linking between multiple data displays where changes in one display (e.g., weight and VGI input pages) are immediately propagated to other displays (age-friendliness map) (Jankowski & Nyerges, 2001; Jelokhani-Niaraki & Malczewski, 2015b).

Finally, the usability of the proposed system for participatory age-friendliness assessment of urban environments was evaluated by the elderly and regular citizens. Being aware of citizens' satisfaction and using their views, criticism and recommendations can help further improve the system. An online survey tool was included in the system to receive citizens' feedback on the effectiveness of the system. To this end, a set of multiple choice questions were presented to users. The questions were related to the general efficiency of such systems in the age-friendliness assessment of cities.

3. Results

The elderly population in district # 6 of Tehran were invited, via announcements in public parks, to participate in criteria comparison tasks and generate individual weights. A total of 50 senior citizens participated in assessing the criteria relevant to the age-friendliness of the urban district at three different times (see Table 2). The proposed system was introduced to the elderly citizens; and they were asked to enter their preferences with respect to the criteria. However, some of the elderly participants, due to their inability and/or inadequate level of knowledge/expertise, found it difficult to understand the concepts and applications of the system. Since they were not familiar with these tools, other age groups familiar with the tools were asked to conduct the pairwise comparisons of criteria on behalf of the elderly and enter them into the system. Eventually, the individual sets of criteria weights were determined using the BWM from the pairwise comparisons.

In order to demonstrate the dynamic aspect of the age-friendliness map, the elderly’s group weights were determined at three sequential times. The group weights changed over time based on the refinement of existing elderly’s weights and/or addition of the new elderly’s weights to the group weights. They were updated over a period of time as each elderly participant refined his/her existing weights and/or when sets of weights were added by new participants. With the progress of time, more elderly and regular citizens participated in the age-friendliness assessment process. This in turn led to more accurate and up-to-date results. At the end of the elderly’s participation period (the third time), 50 sets of weights were used as input for the assessment process. As already mentioned, the sets of criteria weights were aggregated using the geometric mean method (see Table 3). According to the elderly's point of view (third time), the “Distance from health care and medical services” and “safety” criteria were the most important factors affecting the age-friendliness of the city. This is confirmed by WHO (2008), which has recognized the critical role that primary health centers play in the health of older persons in all countries and the need for these centers to be accessible and adapted to the needs of older populations.

Figs. 6 a, b and c show age-friendliness maps according to the group weights and VGI at three consecutive times. The maps were generated based on the primary geographic data (the data related to urban...
infrastructures such as highways which usually change during long time periods), the VGI fed to the system by regular citizens (the data related to changes in urban conditions and services which usually occur in short time periods) and the group weights of the criteria. The final map generated at the third time period indicates the center of the study area as more age-friendly than the other areas. This is most probably due to the concentration of different services, particularly health care and medical services in the central areas. Since the largest weight (0.25)
was assigned to the “Distance from health care and medical services” criterion, it has the greatest effect compared to the other services on the age-friendliness of the areas. Moreover, a high level of accessibility to transportation services has been provided in this area. Contrary to the central part, the south, especially southeast sectors of the study area show a lower level of age-friendliness as opposed to other areas. These areas exhibit undesirable conditions with respect to most of the criteria. Due to noise pollution, low safety, and inadequate accessibility to health care and medical services, the quality of elderly life in these areas are worse compared to the other areas. The northern neighbourhoods show a relatively moderate level of age-friendliness compared to the southern neighbourhoods due to their relatively good conditions with respect to all of the criteria.

In order to perform sensitivity analysis, the overall score of alternatives/locations in the age-friendliness map were classified into five classes of Very low (0.0–0.2), Low (0.2–0.4), Medium (0.4–0.6), High (0.6–0.8) and Very high (0.8–1). Sensitivity analysis was applied to the area classified as Very high (0.8–1) (Gorsevski et al., 2013). The procedure was to vary a single weight, rerun the GIS-MCDA model, and record the corresponding changes in the areas. Changes in the areas of the Very high class was recorded by gradually increasing and decreasing the weights of the seven criteria at 10 percent increments (±10%). Fig. 7 shows the sensitivity of the areas in the Very high class to changes in the criteria weights. The sensitivity results show significant changes in the areas with a mere 10% increase in the weights of distance from green spaces and public services. Another significant change in the areas is observed when the weight of the pollution criterion is decreased by 10%. Since the areas of the Very high class are

Table 2
Summary of participant characteristics.

<table>
<thead>
<tr>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>22</td>
</tr>
<tr>
<td>Male</td>
<td>28</td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>0–65</td>
<td>34</td>
</tr>
<tr>
<td>Over 65</td>
<td>16</td>
</tr>
<tr>
<td>Education</td>
<td></td>
</tr>
<tr>
<td>High school</td>
<td>8</td>
</tr>
<tr>
<td>Diploma to Bachelor</td>
<td>36</td>
</tr>
<tr>
<td>Master- Doctoral</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 3
The geometric mean of criteria weights obtained from the elderly’s pairwise comparisons in three consecutive times.

<table>
<thead>
<tr>
<th>Distance from health care and medical services</th>
<th>Distance from public services</th>
<th>Pollution</th>
<th>Distance from public transportation</th>
<th>Neighbourhood walkability</th>
<th>Distance from green spaces</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>First time</td>
<td>0.25</td>
<td>0.10</td>
<td>0.13</td>
<td>0.10</td>
<td>0.07</td>
<td>0.15</td>
</tr>
<tr>
<td>Second time</td>
<td>0.26</td>
<td>0.12</td>
<td>0.15</td>
<td>0.09</td>
<td>0.08</td>
<td>0.13</td>
</tr>
<tr>
<td>Third time</td>
<td>0.25</td>
<td>0.11</td>
<td>0.14</td>
<td>0.10</td>
<td>0.07</td>
<td>0.14</td>
</tr>
</tbody>
</table>
sensitive to one or more weights, the accuracy in estimating weights should be examined carefully (Malczewski, 1999). In contrast, no significant changes were found in the areas of the Very high class as a result of changes (from -10% to +10%) in the weights of distance from public transportation and neighbourhood walkability. Thus, the best areas in the age-friendliness map are not essentially sensitive to small changes (10%) in these weights.

A total of 40 elderly individuals other than those involved in the system were recruited to rank the six neighbourhoods of district # 6 of Tehran via questionnaire. Fig. 8 shows the neighbourhoods ranked in order of age-friendliness according to responses of the 40 elderly and the Borda method. It is evident from the figure that the northern neighbourhoods are more age-friendly than the southern neighbourhoods. This is consistent with the age-friendliness map generated using the PPGIS (Fig. 6c) which indicates a higher level of age-friendliness for the three northern neighbourhoods as compared to the southern neighbourhoods. However, future studies might use lower scale geographic units (e.g., urban blocks instead of neighbourhoods) in the Borda-based age-friendliness map to validate the PPGIS-based age-friendliness map. This state is referred to as the Modifiable Areal Unit Problem (MAUP), where age-friendliness assessment results are influenced by changing the number/size (the scale effect) and shape (the zoning effect) of spatial analytic units (see Malczewski & Rinner, 2015).

By identifying the most suitable scales and zones, the validation results would be more accurate.

Table 4 summarizes citizens’ responses to the usability of the proposed system for assessing age-friendliness of cities. According to the citizens’ views, the system acts as a suitable tool for evaluating the age-friendliness of the city (22%-strongly agree, 46%-agree), collecting the VGI related to the elderly’s urban environment (35%, 38%) and helping urban planners improve the age-friendliness of cities (25%, 42%). Nevertheless, some of the citizens disagreed, maintaining that the system was not: (i) a suitable tool for persuading them to participate in the city elderly-friendliness evaluation process (15%-strongly disagree, 26%-disagree) and (ii) a reliable approach for the evaluation of the city age-friendliness (12%-strongly disagree, 18%-disagree).

4. Discussion

The elderly are the key players in assessing the age-friendliness of urban environments as they are the ones who have detailed local knowledge of the different locales and are highly associated with the reality and the issues surrounding them as opposed to other individuals. One of the fundamental rights in a democratic society is the right of the elderly citizens to participate and assess their environment. The proposed PPGIS-based system facilitates the collaborative or elderly-
The proposed PPGIS can be used for the evaluation of age-friendliness in other cities and countries around the world. It is a generic system and does not involve any model tailored to a specific country or city. The system can be employed to assess the age-friendliness of different neighbourhoods in a particular city only by using the data, and in some cases, the criteria specific to that city. Moreover, it is worth noting that the proposed PPGIS is flexible enough so as to accommodate for a variety of urban quality assessment problems. For example, it can be successfully used to assess the friendliness of urban areas according to other age groups (youth and child) and/or gender of communities.

It is suggested that urban policies could greatly benefit from older people’s participation and contribution, where skills and experience of older people and the attachments they bring to their communities could shape the policies (Simpson, 2010, WHO, 2016, Buñel & Phillipson, 2018). The results obtained from the elderly participation via the proposed PPGIS lead to tangible policy outcomes for the city councils and municipalities to advance “age-friendly” communities and make their cities more age-friendly. Specifically, the group criteria weights derived from senior citizens and the age-friendliness map produced in the PPGIS could support policy recommendations by presenting how and where the city can become more age-friendly, respectively. The group weights of criteria indicate the priority of the needs and preferences of elderly people for having age-friendly environments. For example, according to the elderly’s point of view, the “Distance from health care and medical services” and “safety” criteria were the most important factors affecting the age-friendliness of the city. This shows the need for certain interventions in the form of policies and programmes to improve the health and well-being of older adults by increasing the number, quality and capacity of healthcare services for health promotion, early detection and treatment, rehabilitation, and palliative care of older people (WHO, 2008, Public Health Agency of Canada, 2015). Similarly, protection from criminal activities, violence and other hazardous events in the community can secure the physical health and mental wellbeing of elderly people.

Moreover, the age-friendliness map produced by the PPGIS plays a key role in developing policies aimed at responding to inequities (such as the unequal distribution of services and facilities) in urban areas. It provides a visually effective way for local policy-makers and planners to address the equity dimension of age-friendliness by revealing the inequities across urban areas on the map. There is a need to identify viable and effective policies to improve social and environmental conditions (e.g., health and social services, public transportation facilities, and neighbourhood walkability) in the vulnerable communities (areas with lower value of age-friendliness), and eventually provide equal conditions for tackling disparities across the city. In these cases, successful implementation of age-friendly policies may require substantial change in community infrastructure (e.g., in the quality of the built environment, transportation, and access to a wide range of local resources). Nevertheless, a careful evaluation of the age-friendliness map is necessary to determine which strategies are most effective given the widespread inequalities across and within the neighbourhoods of a city.

Although the proposed PPGIS provides a platform for promoting the engagement of older citizens in age-friendliness assessment of cities, the success of the system is highly dependent on the elderly’ participation in evaluation of the city age-friendliness can be reliable.

Table 4
The citizens’ opinions about the system usability in the evaluation of city age-friendliness.

<table>
<thead>
<tr>
<th>Opinion</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>No idea</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think this system is a suitable tool for evaluating the age-friendliness of the city.</td>
<td>22%</td>
<td>46%</td>
<td>12%</td>
<td>15%</td>
<td>5%</td>
</tr>
<tr>
<td>I think this system is a suitable tool for collecting the VGI related to the elderly’s urban environment.</td>
<td>35%</td>
<td>38%</td>
<td>12%</td>
<td>10%</td>
<td>5%</td>
</tr>
<tr>
<td>I think this system helps urban planners improve elderly’s urban quality of life.</td>
<td>25%</td>
<td>42%</td>
<td>20%</td>
<td>10%</td>
<td>3%</td>
</tr>
<tr>
<td>I think this system is a suitable tool for persuading citizens to participate in the city elderly-friendliness evaluation.</td>
<td>10%</td>
<td>19%</td>
<td>35%</td>
<td>26%</td>
<td>15%</td>
</tr>
</tbody>
</table>

I think people’s participation in evaluation of the city age-friendliness can be reliable.
as well as their awareness, motivation and knowledge on how to use the system. The wider participation of the elderly and their awareness of and familiarity with the age-friendliness assessment problem can lead to the success of the PPGIS. Consequently, the local and municipal governments wishing to continuously assess and improve the age-friendliness of their cities, need to develop a set of well-developed public participation policies to involve the elderly in the age-friendliness assessment process. For example, municipalities may develop motivational policies for promotion of elderly participation by providing supportive social atmospheres and financial incentives (e.g., waiving the insurance costs) as well as establishing elderly volunteer corps (WHO, 2007, 2016).

Although PPGIS is one of the promising solutions for age-friendliness assessment of cities, it acknowledges a few limitations that should be taken into account. One of the main limitations is the fact the elderly may not be able to effectively use the system. They find it difficult to understand and use the components of the system due to their lower cognitive abilities, inadequate knowledge of new information technologies, lack of familiarity with the age-friendliness assessment problem, etc. Pánek (2015) developed a decision support tool, called ARAMANI, for selecting the optimal participatory mapping method, taking into account the specific needs and assets of the community. Future studies might consider such tools for identifying and employing the most appropriate PPGIS methods for the age-friendliness assessment process.

The results obtained about the usability evaluation of the proposed PPGIS have practical implications for further PPGIS designers to improve the age-friendliness assessment systems. Findings pointing to how some citizens were not satisfied with the usability of the PPGIS tool are consistent with the results reported by previous studies (e.g., Sidlar & Rinner, 2007; Meng & Malczewski, 2010; Jelokhani-Niaraki & Malczewski, 2015a; Rzeszewski & Kotus, 2019). The results of previous studies show that the initial developments of PPGIS tools do not typically meet the usability goals, and need further improvements according to the citizen preferences. In an empirical study, Pánek (2015) found that there is an inverse relationship between the level of participation and technological advancement of the chosen method. In other words, the more technologically challenging a chosen method is, the more technologically challenging a method is, the more challenging a method is, the more technologically challenging a chosen method is, the more difﬁcult it will be to ensure a sufﬁcient level of involvement of the target group. This encourages a deep usability evaluation and a process to validate the design of PPGIS tool in relation to the needs determined by the elderly community, where system goals, objectives, context, and environment are all aligned with the elderly preferences.

Moreover, the ﬁndings that some citizens disagree about the reliability of the PPGIS tool may be related to the quality of participatory data or VGI (Brown, Weber, & De Bie, 2014; Kahila-Tani, Kyutta, & Geertman, 2019; Rzeszewski & Kotus, 2019). Although VGI can be used as a complementary source to primary geographical data in the GIS-MCDA process, this data may suffer from inadequate quality (Ostermann & Spinsanti, 2011; Elwood, Goodchild, & Sui, 2012; Goodchild & Li, 2012; Upton, Ryan, O’Donoghue, & Dhubbain, 2015). Even though the VGI is free and dynamic, the data may not possess a high quality. Since regular citizens are characterized by varying levels of expertise, education, knowledge and experience in using GIS, it is inevitable that they draw the geographic features with topological and geometric errors. A couple of studies introduce systematic approaches to measure the accuracy and assess the quality of VGI (e.g., Goodchild & Li, 2012). Omidipoor, Jelokhani-Niaraki, and Samany (2019) argue that incorporation of topological integrity rules in the participatory GIS provide an automated method for detecting the topological errors of citizen-recommended polygons and cleaning them. Thus, future systems should provide automatic and smart tools for validating the citizen-generated geographic data in the age-friendliness assessment process.

It is important to make sure that GIS-MCDA techniques are used in such a way that their fundamental concepts are understood and assumptions are met (Borouchaki & Malczewski, 2010a; Jelokhani-Niaraki & Malczewski, 2015b). In a PPGIS, however, the elderly people use the GIS-MCDA methods without being fully aware of their meaning. The elderly participants who are not familiar with evaluation methods may have wrong interpretations of the method, criteria, weights, etc. Carver (1999) asserts that the participants feel a certain lack of confidence in any PPGIS when they have difficulty understanding the techniques, concepts and rationale behind that application, such that they cannot use the system efficiently. Jankowski and Nyerges (2001) argue that an effective PPGIS has to provide tools that allow novice and lay citizens to perform analytical tasks equal to expert users. So it is necessary that some people act as representatives and input the people’s opinion into the system or intelligent decision aids be designed to support processes of the elderly’s decision making. The effective use of PPGIS tools by novice and non-expert people has inspired research on integrating PPGIS and intelligent decision aids (Jelokhani-Niaraki & Malczewski, 2012, Jelokhani-Niaraki, 2018). Jelokhani-Niaraki and Malczewski (2012) proposed the concept of Web 3.0-based intelligent PPGIS based on a multi-agents paradigm and semantic technologies, where software agents are able to intelligently act on behalf of users and understand, communicate, reason, and analyze the information in a PPGIS project (see also Bennett, Wade, & Armstrong, 1999). The agents could be made aware on how and when to implement specific GIS-MCDA operations on behalf of the elderly (Jelokhani-Niaraki, 2018).

The successful implementation and the practical application of a PPGIS project depends on a variety of social factors. A PPGIS project is not entirely a matter of system design and development but is rather conditioned by rules, laws, standards, culture, politics, and history of the community, city, region, or nation in which it is used (Carver, 2003, Sieber, 2006, Hardy, 2015). Consequently, the acceptance of PPGIS by the elderly and regular citizens for age-friendliness assessment may vary greatly from city to city or even district to district. While the PPGIS may be largely accepted by all elderly people in one city, the same system may be unacceptable in another city. This also applies to this study and affects how the present findings are generalized (e.g., the weights and system evaluation results). It would be desirable to examine the usability of the system in different cities and by different elderly participants.

5. Conclusion

The evaluation of city age-friendliness is considered a fundamental step in promoting the elderly’s urban quality of life. This paper presents the design and implementation of a Web-based PPGIS for assessing age-friendliness of cities. The proposed system integrates the capabilities of GIS, MCDA, and VGI into the Web platform to provide appropriate spatial analysis and decision support tools for the age-friendliness assessment process. Integration of GIS and MCDA capabilities into the Web platform offers an open, decentralized, public, asynchronous, distributed, and active platform for public participation in age-friendliness assessment processes. The motivation behind integrating GIS with MCDA was that these two areas of research could complement one another during the age-friendliness evaluation processes (Malczewski & Rinner, 2015; Jelokhani-Niaraki, Sadeghi-Niaraki, & Choi, 2018). While GIS has been considered as a powerful and integrated tool with exclusive abilities for storing, manipulating, analyzing and visualizing geographic information, MCDA could provide a wide variety of methods and algorithms for evaluating the age-friendliness of cities. In this study, the combination of BWM and WLC was used as the MCDA method to generate age-friendliness maps. The BWM requires fewer pairwise comparisons compared to other methods. Thus, it is suitable for non-expert people such as the elderly. Age-friendliness map changes over time based on changes in the elderly’s opinions, addition of the new elderly’s opinion and geographic information (i.e., VGI) related to the urban environment. The use of VGI provides an added value for age-friendliness analysis of the urban areas. Contrary to conventional GIS-MCDA approaches, which use authoritative and static sources of data,
VGI-based GIS-MCDA uses dynamic user-generated geographic data to generate criteria maps for age-friendliness analysis.

For future research, it is recommended that elderly-friendliness of cities be evaluated using additional criteria and different MCDA methods. It would be desirable to compare the results with each other. Nowadays, the increasing growth of smartphones equipped with GPS and online social networks provide effective tools for citizens’ participation in resolving urban issues. Future research can provide more effective and user-friendly tools to evaluate city elderly-friendliness through integrating PPGIS into mobile devices or social networks. For example, Goodchild (2007) suggests that GPS provides important capabilities in collecting VGI through walking, cycling, and driving. Thus, smartphones equipped with GPS provide citizens with the ability to enter the geographic data related to the city environment into the system using any network, in any place, and at any time. This phenomenon facilitates the process of evaluating and monitoring the elderly-friendliness of a city.

References

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