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# User-centered AI-based voice-assistants for safe mobility of older people in urban context

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**Abstract**
Voice-assistants are becoming increasingly popular and can be deployed to offers a low-cost tool that can support and potentially reduce falls, injuries, and accidents faced by older people within the age of 65 and older. But, irrespective of the mobility and walkability challenges faced by the aging population, studies that employed Artificial Intelligence (AI)-based voice-assistants to reduce risks faced by older people when they use public transportation and walk in built environment are scarce. This is because the development of AI-based voice-assistants suitable for the mobility domain presents several techno–social challenges. Accordingly, this study aims to identify *user-centered* service design and functional requirements, techno–social factors, and further design an architectural model for an AI-based voice-assistants that provide personalized recommendation to reduce falls, injuries, and accidents faced by older people. Accordingly, a scoping review of the literature grounded on secondary data from 59 studies was conducted and descriptive analysis of the literature and content-related analysis of the literature was carried out. Findings from this study presents the perceived techno-socio factors that may influences older people use of AI-based voice-assistants. More importantly, this study presents user-centred service design and functional requirements needed to be considered in developing voice-assistants suitable for older people. Implications from this study provides AI techniques for implementing voice-assistants that provide safe mobility, walkability, and wayfinding for older people in urban areas.

**Keywords** Safe mobility · Techno–social factors · User-centered design · Service design and functional requirements · AI-based voice-assistants · Older people

## 1 Introduction

According to the World Health Organization (WHO), it is estimated that the world population consisting of older people will reach 22% by 2050 (da Paixão Pinto et al. 2021), with most older people living alone in their homes (O'Brien et al. 2020). Mobility inaccessibility, falls, injuries, and accidents are risks faced by the older people (Older people defined here as those aged ≥ 65 years and older (between the age of 65–74, 75 and older)) (Gudala et al. 2022). Digitalization employing Artificial Intelligence (AI) driven techniques can support mobility accessibility to be safe. Voice-assistants may be one type of AI technology that can improve the safety of older adults in urban environment (da Paixão Pinto et al. 2021). AI-based voice-assistants uses Natural Language Processing (NLP) to communicate with users, Machine Learning (ML), and speech recognition to process requests from users. Therefore, AI-based voice assistants have been adopted to improve tasks such as self-management in healthcare for older people (Capodieci et al. 2018). Also, the deployment of AI allows older people to speak to and receive in-context responses from a computer system similar to humans to human interactions (McLean and Osei-Frimpong 2019).

Even though the technological and digital knowledge of older people are improving, some physiological changes occurs as we get older such as decrease in coordination linked to vision, hearing, and sensitivity of finger and hand. These AI-based voice assistants are programmed to provide responses when receiving questions from individuals. As

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they are in constant learning process through the experience acquired by interactions with datasets or users (da Paixão Pinto et al. 2021). By using AI-based voice-assistants' older people do not need to always use the interface, mouse, or keyboards to gather information on mobility and navigation when they go walking; instead, they can ask the AI-based voice-assistants for available and accessible mobility modes and receive the information as recommendations verbally via an audible interface (O'Brien et al. 2020). AI-based voice-assistants are still a new technology and *the use of this technology by older people is still in an investigative phase. Thus, there is need to identify user and system design requirements needed for successful implementation* (Arnold et al. 2022). *Similarly, the deployment of AI-based voice-assistants in real world applications is challenging due to design requirements*. Also, these AI based systems have to understand human languages and learn from communications, increasing its knowledgebase (Tascini 2018), in some cases, it has to remotely connect with family members, care givers, and emergency department when older people fall.

In addition, existing technological tools provided to the aging population fail to consider the changing needs of older people, for example by avoiding small font sizes and use of poor color contrast on user interfaces (Wedberg and Dalgren 2021). *Thus, older people face several techno–social challenges that influences the use of this technology* across aging population. As such an architectural model-based approach is required to fill the current knowledge gaps regarding the AI techniques needed to support the *user-centered* implementation of AI-based voice-assistants. Therefore, this article will investigate the following research questions:

- Which user-centered service design and functional requirements are important when implementing AI-based voice-assistants for older people?
- Which techno–social factors may influence the use of AI-based voice-assistants by older people?
- What AI techniques are suitable to design an architectural model for a voice-assistants that provide information to older people for safe mobility and walkability?

Therefore, this study aims to identify from the literature the techno–social factors that may influence older people use of AI-based voice-assistants and further investigates the service design challenges, particularly concerning those who are 65 years-plus. Hence, this study contributes by presenting the user-centred design requirements that an AI-based voice-assistants should cover according to todays and future mobility and walkability needs suitable for older people in the society. *The AI-based voice-assistants employ AI techniques such as ML, NLP, and speech recognition to learn from interactions, provides answers to older people questions*. The vision of this study is to design an architectural model that can be employed to develop ubiquitous and proactive AI-based voice-assistant system that delivers personalized mobility and walkability support in the form of conversation aimed at promoting safe mobility for older people. The architectural model is designed in order to use real-time data with high-level abstractions in *ML and NLP*. A key contribution of the architectural model involves the provision of personalization of conversation grounded on the basis of older user's mobility needs which can be developed using explicit (e.g., information entered by the user) as well as implicit (e.g., activity data collected with the user consent from their physical devices such as smart mobile, wearable devices, etc.). The rest of this article is structured as follows. Section 2 discusses theoretical background. Section 3 presents the methodology. Section 4 reports the findings, and Sect. 5 is the discussions and implications. Finally, Sect. 6 is the concludes the study.

## 2 Theoretical background

### 2.1 Background of AI-based voice-assistants

Voice-assistants are automated applications that enables human-to-computer interaction via text or natural language (García-Méndez et al. 2021). Voice-assistants are programmed to reply to certain inputs thereby resulting to user feedback (Tascini 2018). They are able to recognize natural language and continuously learn from interactions, becoming progressively intelligent (Tascini 2019). A common method to voice-assistant development is to pre-program questions and phrases to respond to individuals input in the form of words, phrases, and questions. Additional contents are routinely added to improve the knowledge on the dialogues held (García-Méndez et al. 2021). One of the strengths of voice-assistants is their capability to be always active and to be self-contained to provide individuals with responses and help. In general, voice-assistants have three key components which comprises of a *user interface, a normaliser, and a knowledge base*. Recently AI-based voice-assistants has surfaced which has the ability to create conversation between a digital agent and a user. As such, voice-assistant have been progressed through easy standalone intelligent home devices and application integrated in smart phones (e.g., Microsoft's Cortana, Google Assistant, Amazon Alexa, Apple Siri, etc.) (Wiratunga et al. 2020).

AI enabled voice-assistants are developed based on the personalities of machine learning models combined with natural language programming (García-Méndez et al. 2021). AI-based voice-assistants uses speech recognition which are systems that have the ability to collect and interpret spoken information by converting the inputted voice command to text. Existing speech recognition systems such as Microsoft's WisperID that recognize what is being said but also recognizes the particular speaker (https://www.microsoft.com/en-us/research/project/speaker-identification-whisperid/), in situation where different vowel sounds or accents from different sound origin are analyzed to recognize the speaker (Wedberg and Dalgren 2021). Indeed, AI-based voice-assistants is being adopted as a potential aid for older people due to early-stage adoption of such applications for health management, though these systems are in use due to improved readiness level many barriers still remain that impacts their successful adoption by the aging population (Gudala et al. 2022). It has been adopted in different areas such as in e-commerce, healthcare, weather reporting, reading news, play music, etc. by older people. AI-based voice-assistants use a microphone embedded in a device to receive commands from the user's voice, and it converts the inputted voice into a text sentence (utilizing a natural language parser), and it executes the suitable command stated within the sentence. As output, AI-based voice-assistants uses a speaker embedded in a physical device to communicate response to individuals as the outcome of the command based on ML models (Capodieci et al. 2018).

These ML models possess the capability to understand spoken human language learn and adapt from the interactions, thereby increasing the knowledgebase (Anthony Jnr 2021), enabling the system to recall tasks assigned and personalization, connect remotely with family members and caregivers. AI-based voice-assistants are useful to improve the welfare and well-being of older people by increasing their quality of life. AI-based voice-assistant are intelligent software that can learn from prior experience using ML algorithms and NLP (Tascini 2019). Due to the advancement of AI enabled voice-assistants to intelligently generate responses to end user requests it is now being adopted by older people in different domains such as healthcare, weather, news, etc. (de Arriba-Pérez et al. 2021; Gudala et al. 2022; Miura et al. 2022). *Nevertheless, studies that examines the use of AI-based voice-assistants to provide personalized real-time information to reduce falls, injuries, and accidents faced by older people is scarce. Similarly, there are few studies that investigate how AI-based voice-assistants can improve safe mobility and walkability and possibly walkability for older people in urban context. Thus, there is need for studies that address these aforementioned setbacks.*

## 3 Methodology

A scoping review methodology was adopted in this study and secondary data was collected from the literature. The process suggested by Higgins and Green (2011); Colquhoun et al. (2014) was employed for carrying out scoping reviews and for searching of the literature. The identified process comprises identifying of the research question(s), specifying relevant studies, choosing the studies, charting the secondary

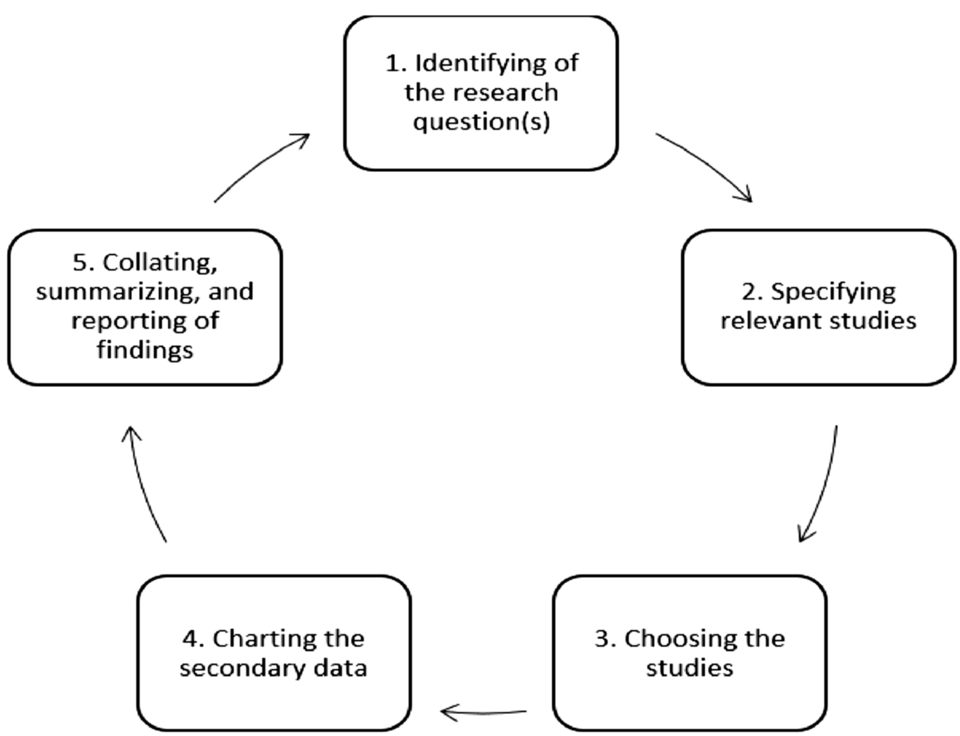


**Fig. 1** Scoping review process

data, and lastly collating, summarizing, and reporting of findings (Furlan et al. 2020), as seen in Fig. 1.

Figure 1 depicts the overall scoping review methodology process employed. In addition, scoping review was carried out in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) reporting guidelines (Tricco et al. 2018). At the beginning of this review, the corresponding author formulated the research questions as seen in the introduction section of this paper and the search terms to guide the direction of the study area.

### 3.1 Inclusion and exclusion criteria

In accordance with the procedures for conducting scoping reviews (Higgins and Green 2011; Colquhoun et al. 2014; Tricco et al. 2018), published studies related to “safe mobility and walkability for older people”, “reduction of falls, injuries, and accidents by older people”, and “AI based voice-assistants use by older people” were considered for inclusion. Also, studies that employed any type of research design such as quantitative, qualitative, review, experiments, modeling, prototyping, and simulation were considered for inclusion. This study also includes studies published as peer-reviewed journal articles, conference proceedings, policy reports, and book/book chapters since the study area is vast and may be published in other venues. While research in the study area could have been carried out in different countries only those published in English languages were selected. Different sources were sampled such as literature reviews, original research papers, etc. similar to prior studies (Furlan et al. 2020; Niemann et al. 2023; Anthony Jnr 2021), to ensure that no key information published by prior studies are missed and this helps to reduce biases that may arise in the study selection process.

Studies included relates to older people mobility (i.e., safe, and secure mobility, safe walkability, AI for safe mobility, service design and functional requirements for older people, and techno–social inhibitors). Since this current study relates to older people there was not year restriction for selecting studies but typically studies from 2000 till date (2023) were seen as more favorable. Moreover, studies were included if reporting outcomes relates to use of AI-based voice-assistants for older people in different domains to draw inference on the state-of-the-art on the uptake and adoption of AI technology use among the aging population. Also, studies which aim/objectives explored measures to improve safety of older pedestrians or safety in use of public transportation by older people as related to reduction of falls, injuries, and accidents were also included. Studies were excluded if the aim/objectives are not related to safety of older people (i.e., safety of other vulnerable road users). Studies were also excluded if they are not aligned to older people in the society.

### 3.2 Databases searched

Extensive searches were conducted in the following online libraries and databases: Google Scholar, Web of Science, and Scopus. Other online libraries such as ScienceDirect, linkSpringer, emerald insight, IEEE xplore, SagePub, Taylor & Francis e-library, Wiley online library, Inderscienceonline, Compendex (Engineering Village), and Social Science Abstracts (EBSCO) were searched to retrieve studies related to the study area.

### 3.3 Search terms

The search terms were established based on the title, keywords, abstract, and research questions. The following search queries were applied based on the title, keyword, and abstract.

- (“falls” OR “injuries” OR “ accidents”) AND (outdoor mobility* OR walkability OR wayfinding) AND (safety OR independence OR accessibility) AND (older people OR older adults OR elderly OR senior citizens OR aging population))
- (“voice-assistants “ OR “personal assistants” OR “ virtual assistants”) AND (safe outdoor mobility* OR safe walkability OR safe wayfinding) AND (safety OR independence OR accessibility) AND (older people OR older adults OR elderly)
- (“AI” OR “artificial intelligence” OR “machine learning” OR “natural language processing” AND “mobility” AND “walking” *) AND (“older people” OR “older adults” OR “elderly” OR “senior citizens” OR aging population*)
- (“user-centred” AND “service design requirements” AND functional requirements*) AND (voice-assistants OR "personal assistants" OR " virtual assistants"*)
- (“factors” AND “inhibitors” AND challenges*) AND (“voice-assistants” OR "personal assistants" OR " virtual assistants"*)

All searches were carried out from during March 2022 and then in August 2023 to revise the literature related to safe mobility and walkability of older people related to the mitigation of risk related to falls, injuries, and accidents.

### 3.4 Selecting studies

Based on the PRISMA reporting guidelines (Tricco et al. 2018), Fig. 2 shows the studies selection process. The PRISMA method was adopted as employed by prior review

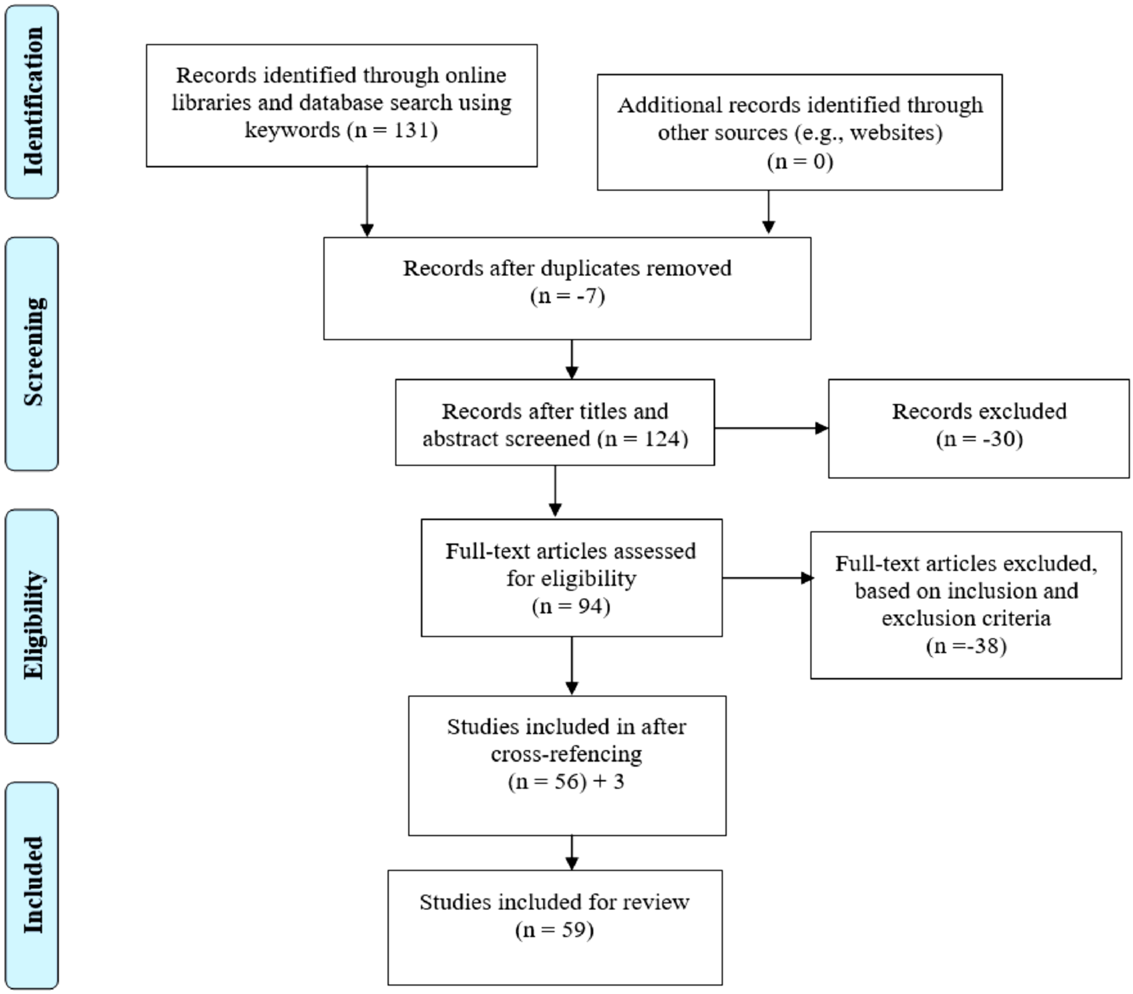


**Fig. 2** Overview of the search process for the identified of studies

studies (Furlan et al. 2020; Anthony Jr 2023; Niemann et al. 2023). The early search yielded 131 potential studies were retrieved from the online libraries and databases as seen in Fig. 2 using the above-mentioned keywords. 7 articles were found as duplicates and were deleted. Once duplicates were excluded a total of 124 studies remained which titles and abstract were screened to be in line with the study area of "voice-assistants for older people or older adults" and "safe mobility and walkability for reduced falls, injuries, and accidents". Then 30 studies were deleted as the titles and abstract were not aligned to the study area resulting to 94 studies which were approved for the full-text assessment. In this phase, all the studies' contents were checked to be related to the research questions. At the point no studies were removed. Then the remaining 94 studies were checked against the inclusion and exclusion criteria (as discussed in Sect. 2.1). Thus, 38 studies were excluded as these sources did not meet the inclusion criteria (see Fig. 2 for the PRISMA flow diagram). A total of 56 studies met the inclusion criteria and were included in the analyses. After which 3 studies were added (Higgins and Green 2011; Colquhoun et al. 2014; Tricco et al. 2018), to guide the review process resulting to a total of 59 studies. The references to all 59 included studies are presented in the reference section of this article.

### 3.5 Data extraction

Next, the selected studies were analyzed, extracted, and synthesized to provide secondary data on the research questions being examined in the study using descriptive and content analysis. As suggested in prior study Furlan et al. (2020) a spreadsheet was created using Microsoft Excel to extract and input data from all the included sources. Then the extracted data in spreadsheet were compared and clustered in themes based on the research questions being explored in this study for consistent coding across categorized themes in the spreadsheet. In the next phase of the data extraction process, secondary data were assigned to each theme in relation to the corresponding information independently extracted. The following thematized information was extracted from each included sources when available: study types, year of publication, country of the publishing research institution, methodology employed, and research domain. Secondary data was also collected and thematized based on service design and functional requirements, techno–social factors, architectural model components and AI-based techniques for voice-assistants in relation to the research questions in this study. Data extraction and synthesis was completed in August 2023. Then, charts and graphs were created to capture the distributions and frequency of the evidence as related to the selected sources as reported (*as descriptive analysis of the literature*). In addition, findings related to the research questions were reported (*as content-related analysis of the literature*).

## 4 Findings

### 4.1 Descriptive analysis of the literature

Pivot tables, graphs, and different charts were created in Microsoft Excel to capture the distributions and frequency of evidence from the secondary sources as recommended in the literature (Furlan et al. 2020; Niemann et al. 2023). Descriptive statistics were employed to report frequency, proportions, and percentage of the selected studies, where possible analogous to prior studies (Furlan et al. 2020; Niemann et al. 2023; Anthony Jr 2023). Thus, descriptive analysis of the selected studies is conducted with focus on the distribution of study types, year of publication, country of the publishing research institution, methodology employed, and examined research domain carried out in the selected studies.

Findings from Fig. 3 presents the distribution of the selected 59 studies, where 52% ($N=31$) are journal articles, 29% ($N=17$) are conference proceedings, 8% ($N=5$) are project/policy reports, books/book chapters are 7% ($N=4$) and lastly 2% ($N=1$) are thesis reports and preprint, respectively. This finding suggests that there is need for more rigorous studies published in peer-reviewed journal as only 52% of such works has been published as related to the study areas of safe mobility and walkability, reduction of falls, injuries, and accidents, and AI-based voice-assistants use by older adults in different areas.

Findings from Fig. 4 suggest that majority of the included studies was published in 2021 with $N=12$, followed by 2020 with $N=9$. 2019 and 2022 recorded $N=6$ studies were published related to safe mobility and walkability, reduction of falls, injuries, and accidents, and AI-based voice-assistants use by older adults in different research domain. Surprisingly 2023 had $N=5$ studies, and 2018 recorded with

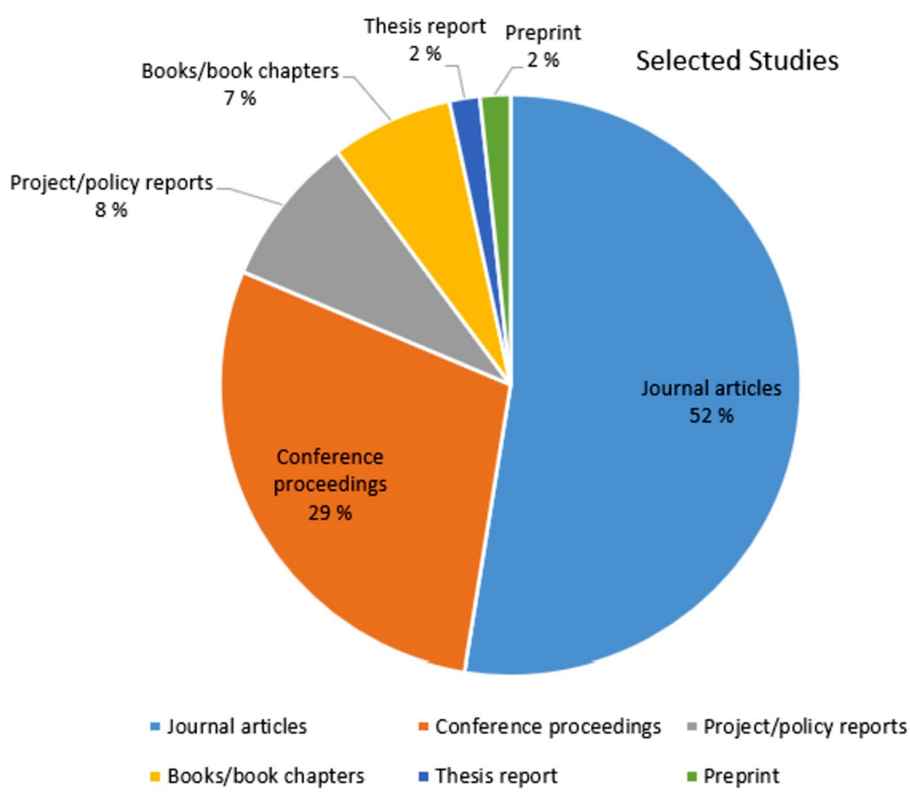


**Fig. 3** Distribution of selected studies

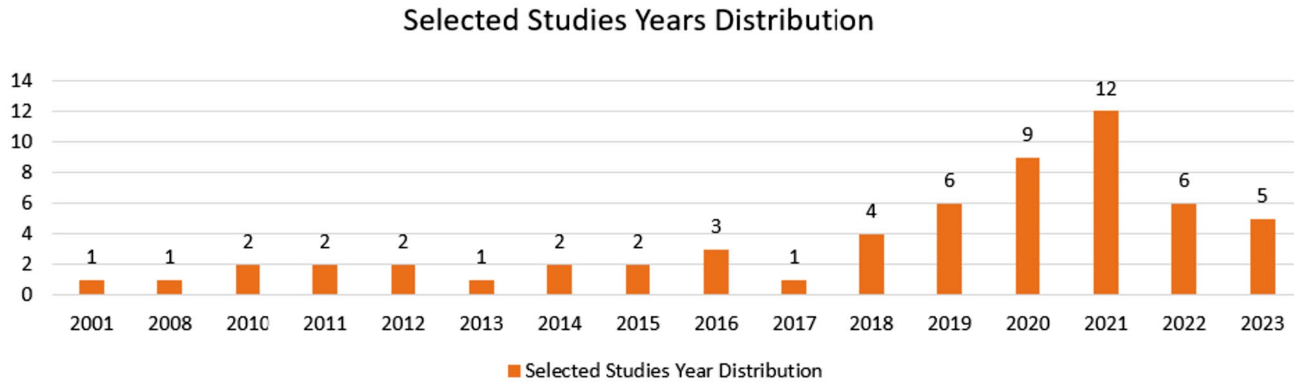


**Fig. 4** Distribution of selected studies year distribution

$N=3$. 2016 recorded $N=3$ and 2010, 2011, 2012, 2014, and 2015 had $N=2$ individually. Lastly 2001, 2008, 2013, and 2017 recorded that only $N=1$ studies related to the study areas were published individually. This finding suggests that fewer studies have been published in this important area and this necessitates more research related AI-based voice-assistants be used to provide personalized real-time information to reduce falls, injuries, and accidents by older people as 2023 only recorded 5 studies.

Figure 5 indicates that in analyzing the 59 studies, most of the sources included in this article adopted literature review as methodology in their research with 18 sources, followed by experiments with 8 sources and survey questionnaires with 5 sources. Findings from Fig. 5 also show other method employed such as interview with 5 studies. Also 2 studies employed interviews, daily diary entries, and usage logs, questionnaire and interview, simulation and modelling, and workshops individually. The remaining studies employed other methods as shown in Fig. 5. This result indicates that the use of voice-assistants by older adults across different areas, and safe mobility and walkability for older people is still an emerging subject as such there is need for more empirical research-based studies. Figure 6 shows that a total of 27 countries of the authors based on their publish affiliations. The result suggests that most contributors in the study area are mostly in USA with 16 studies, and Canada and Norway with 7 studies respectively. This is followed

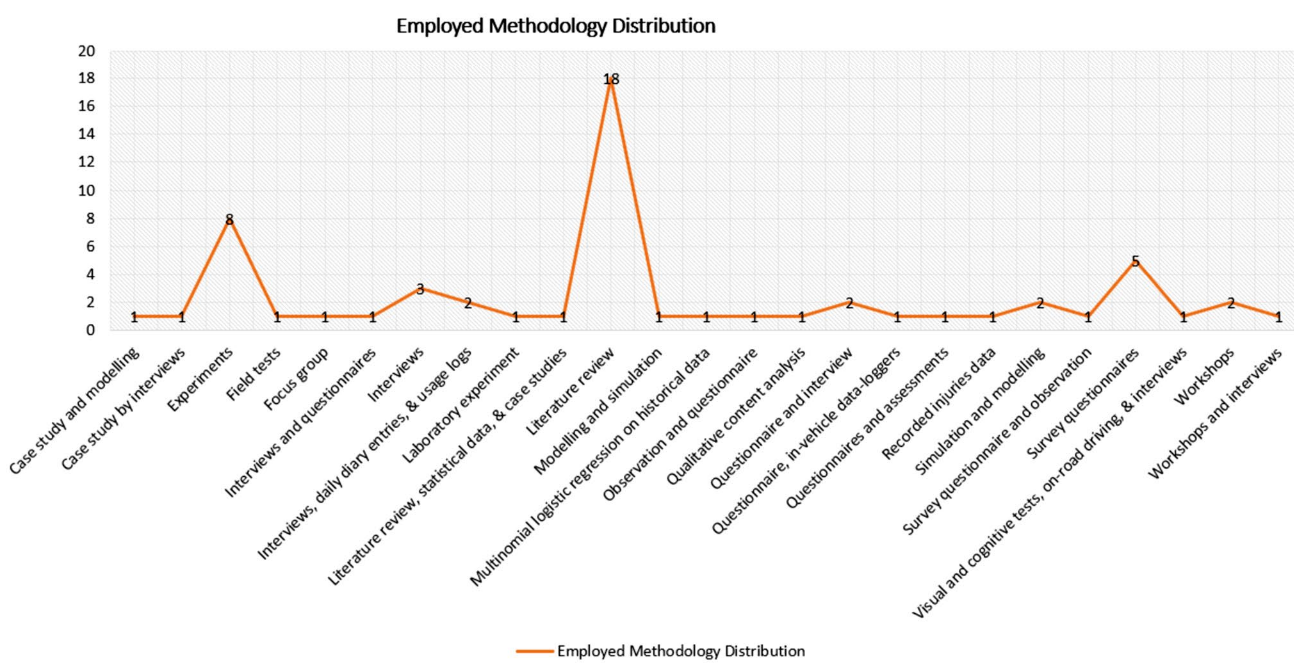


**Fig. 5** Distribution of employed methodology

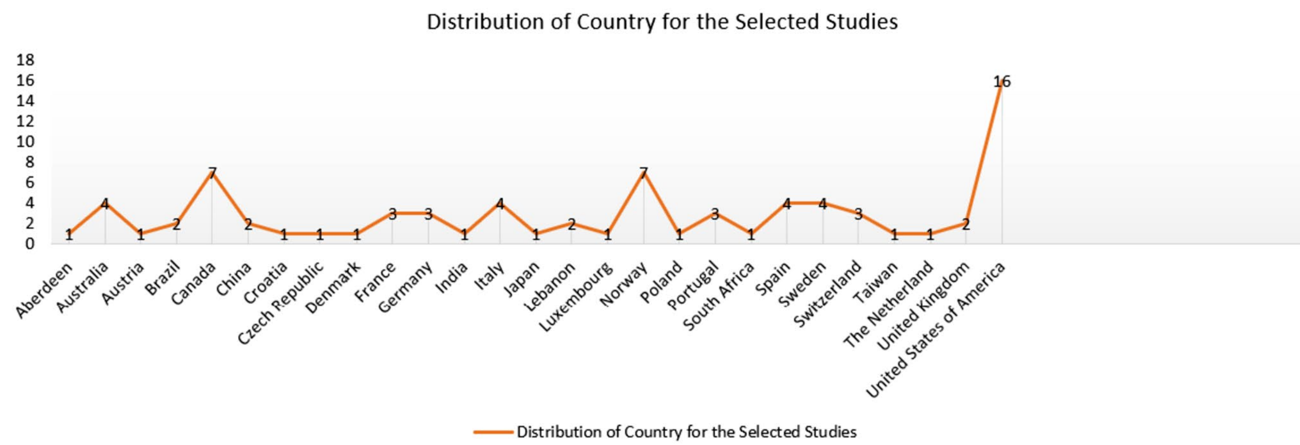


**Fig. 6** Distribution of country of selected studies

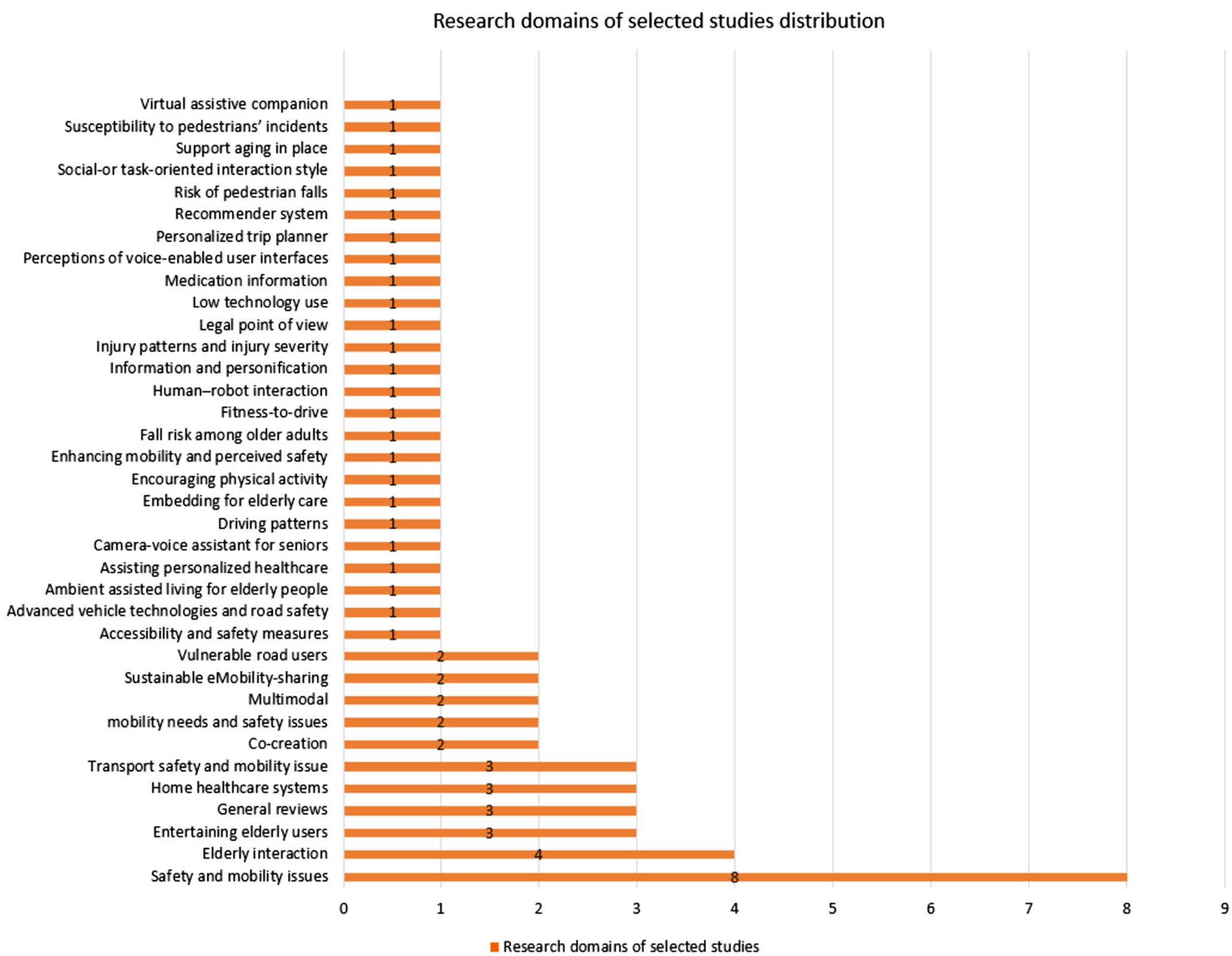


**Fig. 7** Distribution of research domain explored

by Australia, Italy, Spain, and Sweden each with 4 studies included as compared to other countries as seen in Fig. 6.

Furthermore, out of the 59 sources included in this study Fig. 7 summarizes the context of the study examined the selected studies. The result suggests that most of the reviewed study examined safety and mobility issues, elderly interactions, entertaining elderly users, general reviews, home healthcare systems, transport safety and mobility issue. However, only few studies have examined how to mitigate falls, injuries, and accidents of older people in urban areas.

## 4.2 Content-related analysis of the literature

### 4.2.1 Safe mobility needs of older people

In Scandinavian countries such as Norway people above 65 years old accounts for almost two-thirds of all falls, injuries, and fatal accidents. These falls, injuries, and accidents results to mobility exclusion and limits older people from walking especially during the winter and rainy season (Elvik and Bjørnskau 2019), and further account for 64% of older people who require medical care due to injuries that occur when go for walking (Wedberg and Dalgren 2021). The most common falls, injuries, and accidents are as a result of stumbling, slipping, or tripping in the build environment (Elvik and Bjørnskau 2019). This is one of the recurring issues faced by the municipality's health care system that necessitates why the digitization of older people care and coping is so important. Older people often feel alone, as reported in the literature at least one in ten individuals over the age of 75 feel socially isolated, and this is a risk factor for psychological illness (Wedberg and Dalgren 2021). AI based machine learning, natural language processing, speech recognition (spoken dialogue system), image recognition, etc. can be employed to improve safe mobility and walkability for older people to reduce falls, injuries, and fatal accidents. Among these applications, AI-based voice-assistants such as spoken dialogue applications have constantly been a tropic topic over the last years and is commonly used in the society.

AI-based voice-assistants could be designed specifically for older people to accompany older pedestrians and guide them by communicating with them to avoid falls, injuries, and fatal accidents providing suitable responses (Su et al. 2017). AI-based voice-assistants could be a possible solution to reduce cost in care and coping of older people, as it could decrease perceived loneliness and prevent injuries which in turn improves the quality of life for the aging population (Wedberg and Dalgren 2021). Older people with associated motor skills difficulties can beneficially use voice-assistants as they may occasionally have to interact with their voice. The AI-based voice-assistants is also useful for older people with cognitive disorders for example dementia, where the system can make sure that individuals does not forget their direction home when they go walking (Wedberg and Dalgren 2021). *This is why the use of AI-based voice-assistants by older people offers an exciting area to explore further as related to how this technology can be used to reduce falls, injuries, and accidents faced by older people when they go walking and use public transportation in urban environment.* Over the years a few studies have examined how to improve the mobility safety of older people as seen in Table 1.

Prior studies explored strategies to improve safe mobility of older people as discussed in Table 1. *However, studies that investigated the safe mobility and walkability needs of older people in urban context by considering the techno–social perspective, as well as digital technologies such as AI-based techniques (ML, NLP, and speech recognition) can be adopted to reduce falls, injuries, and accidents by older people are scarce*. AI-based voice-assistants can provide personalized real-time information to improve safe mobility and walkability for older people in urban context. Moreover, there are limited studies that explored which user-centered service design and functional requirements are to be considered in developing AI-based voice-assistants suitable for older people to improve safe mobility, walkability, and wayfinding.

### 4.2.2 User-centered service design and functional requirements

*This section aims to address RQ 1: Which user-centered service design and functional requirements are important for developers in implementing AI-based voice-assistants for older people?* Grounded on the secondary data the user-centered service design and functional requirements for AI-based voice-assistants are discussed below.

**4.2.2.1 Service design requirements for older people centric voice-assistants** Services designed for older people have become more required than ever before (Su et al. 2017), as such there is need to identify the functional requirements needed to develop AI-based voice-assistants suitable for use by older people in the society. The service design captures the requirements mainly from the designer's perspective. As such in designing the AI-based voice-assistants the system should comprise of *readily available, low cost, and inexpensive, hardware components* and *open-source software* if possible. It will be beneficial to the society if the integration of AI-based voice-assistants into existing technologies used by older people should be *cost-effective* not incur much increase in cost. AI-based voice-assistants should be designed adhering to *privacy-by-design principles* to improve the security and privacy of older users thereby *establishing users trust* of the system (Chen et al. 2021; Wedberg and Dalgren 2021). Countermeasures can

**Table 1** Related studies on the mobility safety of older people in urban context

| Author(s), year, and contributions | Studied research areas | Methodology | Research context | Countries |
|---|---|---|---|---|
| Niemann et al. (2023) explored the risks of e-mobility based on the injury severity and sustained injury patterns | • e-scooter, and e-bike<br>• e-mobility<br>• Sustainable energy | Literature review | Assessed associated injuries reported to the emergency department related to use of electric personal mobility devices | Germany |
| Doulabi et al. (2021) investigated the causes of older adults' vulnerability to pedestrians' incidents | • Older pedestrians<br>• Falls incidents<br>• Crash involvement | Survey | Aimed to examine the factors that impacts older adults' exposure to pedestrian incidents such as pedestrian-vehicle collisions and falls incidents | United States of America, Canada |
| Du et al. (2020) designed an agent-based simulation approach for evaluating fall risk among older adults during evacuation procedures | • Agent-based models<br>• Crowd safety<br>• Fall risk<br>• Human behavior | Case study, Modeling | Modeled fall risk assessment and fall risk index establishment for older adults amidst an evacuation scenario | Canada, China |
| Furlan et al. (2020) studied road safety based on advanced vehicle technologies | • Driver assistance systems<br>• Age, drivers, and driving<br>• Road safety | Literature review | Highlighted the opportunities as well as the challenges involved with using advanced vehicle technologies to improve road safety | Canada, Australia |
| Jian and Shi (2020) older drivers' action on traffic safety using artificial neural network based on the car-following model | • Elderly driver<br>• Traffic safety<br>• Artificial neural network<br>• Car-following model | Modeling, Simulation | Aimed to quantitatively analyze the impact of older drivers on traffic safety | China |
| Schmeidler (2020) discussed on the area of safe and secure cities targeting senior citizens and pedestrians | • Green transport<br>• Safe and secure cities<br>• Pedestrians<br>• Senior citizens | Literature review | Aimed to improve the mobility of senior citizens in urban environment in relation to green mobility | Czech Republic |
| Vijaya Prakash and Taduri (2020) investigated safe navigation for the visually impaired and older people utilizing adhesive tactile walking surface as indicators within home environment | • Safe navigation<br>• Visually impaired<br>• Older people | Experiments | Aimed to help to improve safe navigation for older people and those with visual impairment in the home environment using 3D printer technology | India |
| Charlton et al. (2019) examined changes in driving patterns of older people | • Crash and serious injuries<br>• Self-regulation<br>• Driving behavior | Questionnaire, in-vehicle data-loggers | Described changes in driving patterns for older people aged 75 years and older over a five-year period | Australia, Canada |
| Elvik and Bjørnskau (2019) examined the risk of pedestrian falls considering gender, age, and walking surface condition | • Pedestrian,<br>• Fall and injury<br>• Snow or ice<br>• Risk of falling | Quantitative analysis of reported injury data | Described the risk of pedestrian injury in falls based on historical data collected within 2016 | Norway |
| Kim (2019) explored transportation safety of older pedestrians and modeled the contributing factors to old-pedestrian collisions | • Elderly pedestrians<br>• Traffic collision<br>• Intersection level<br>• Built environment | Multinomial logistic (MNL) regression on historical data | Assessed the relationship involving physical conditions and old-pedestrian safety mainly at the intersection level | United States of America, Canada |

**Table 1** (continued)

| Author(s), year, and contributions | Studied research areas | Methodology | Research context | Countries |
|---|---|---|---|---|
| Tournier et al. (2016) presented a review of mobility and safety challenges among older pedestrians | • Pedestrians<br>• Aging and safety<br>• Mobility<br>• Functional changes | Literature review | Focused on the main components of old-pedestrian activities which comprises of walking, way finding, obstacle negotiation, and road crossing | Luxembourg, France |
| Peraković et al. (2015) explored the integration of ICT to enhance safe movement of visually impaired and blind persons | • Mobility<br>• Navigation<br>• Assisted technologies | Literature review | Identified and classified important factors required to describe the user's requirements, as basic precondition needed for the design of ICT driven mobility services | Croatia |
| Sochor (2015) researched on improving perceived safety and mobility via ICT for proving a navigation tool for visually impaired people | • Navigation system<br>• Public transportation<br>• Impaired person | Case study by interview | Investigated visually impaired individuals and the possible outcomes of a designed navigation system on their perceived safety and mobility | Sweden |
| Broberg and Willstrand (2014) explored safe mobility for older drivers based on self-assessment and expert | • Traffic safety<br>• Driver behavior<br>• Human factors<br>• Active and preventive safety | Visual and cognitive tests, on-road driving, and interview | Aimed to identify the needs of the older drivers and propose solutions for safe mobility | Sweden |
| Antin et al. (2012) developed a fitness-to-drive model grounded on the comparison of non-drivers and impairment profiles of older drivers | • Functional impairment<br>• Senior mobility<br>• Driver/driving assessment | Questionnaires and assessments | Compared non-driver and older driver functional impairment profiles based on 60 assessment indicators | United States of America |
| Wretstrand and Marin-Lamellet (2011) examined the main quality factor for safety in public transit of mobility-impaired people | • Public transit safety<br>• Passenger injuries<br>• Older and disabled passengers | Literature review | Discussed safety issues in public transit based on different viewpoints (safety and risk management, quality aspect, and safe traveling) | Sweden, France |
| Ball et al. (2013) explored emerging challenges facing sustainable and safe mobility for older persons | • Safe mobility<br>• Safe driving<br>• Mobility independence | Literature review | Advocated for research that maintain safe driving, promote independence and mobility for older people who can no longer drive safely | United States of America |
| Marin-Lamellet-INRETS and Simoes-ISEC (2010) discussed on safe cities for all emphasizing on safety measures for pedestrians with disabilities | • Mobility safety measures<br>• Mobility schemes<br>• Best practice models | Literature review | Aimed at providing useful mobility guidelines and policy recommendations to support accessible public transport for everyone in the society | France, Portugal |
| Oxley et al. (2010) investigated transport safety and mobility concerns for older female drivers | • Older driver and gender<br>• Functional performance<br>• Travel patterns & crash risk<br>• Countermeasures | Survey questionnaire | Researched safety of mobility and travel patterns among older women drivers and older drivers from 60 years and over | Australia |
| Ståhl et al. (2008) discussed safety and accessibility strategies involving elderly people in residential area | • Outdoor environment<br>• Pedestrians<br>• Mobility & urban planning<br>• Community participation | Mixed-method approach (survey questionnaire and observation) | Identify and prioritize specific measures to improve safety and accessibility in outdoor pedestrian area within residential environment | Sweden |

**Table 1** (continued)

| Author(s), year, and contributions | Studied research areas | Methodology | Research context | Countries |
|---|---|---|---|---|
| OECD (2001) discussed mobility needs and safety challenges as related to aging and transport to meet older people's mobility needs | • Mobility and safety issues<br>• Safety standards | Literature review, statistical data, and case studies | Aimed to identify existing and emerging safety and mobility concerns arising from the aging generation and develop policy and research recommendations | France |

be invoked when needed during use as safeguards to ensure that the confidentiality of contextual data and unintended speech are guaranteed as well as establishing trust between older people and the AI-based voice-assistants (Chen et al. 2021). The *information provided* to older people should be accessible to those who are visually impaired to satisfy all the accessibility aspects based on the universal design principles. Therefore, the AI-based voice-assistants application provided to support mobility and walkability has to satisfy older users requirements, and the *selection of colors for the web and mobile application* should be suitable for partially sighted persons or those with vision impairment. The application should *support the reducing or increasing of the font size*.

AI-based voice-assistants should offer more flexibility that enables older users to *change pre-defined settings* such as the name of the voice-assistants, or its speech/auditory interface output configuration like speed, voice, and verbosity of responses and notifications (Abdolrahmani et al. 2021; Burema 2022). Moreover, AI-based voice-assistants should *provide visual output* such as an animation, avatar, personas, cartoon, etc. as this could be valuable for improving the ease-of use and fostering social interaction experience (Pradhan et al. 2019; Chen et al. 2021). As pointed out by Pradhan et al. (2019), in order to know how these personas and avatar should be designed, designers should include the older people who are the users in the creation stage of the AI-based voice-assistants to get older people opinion related to what they want their voice-assistants to do (e.g., mobility support vs. wayfinding information or just walkability guide). The persona of the AI-based voice-assistants for providing mobility support might differ from the one that provides only wayfinding information needs. In addition, evidence from Pradhan et al. (2019) stated that not all users desire a female voice trait for their voice-assistants. The users requested for voice-assistants that provides the *option to change the voice from either male voice to a female voice*.

Moreover, the system should also allow the users such as older people, family members, care givers, etc. to easily *change the factory settings or configurations* based on the mobility and walkability needs of older people (for example enable/disable the auditory interface connected to a specific feature in physical devices such as smartphones). In addition, the visual output should be *user-adaptable or self-adaptive* to provide best interface match to older people ability and desire. *Personalized mobility and walkability suggestions* should be based on older people requirements and needs, and it might be beneficial if the AI-based voice-assistants is designed to provide personalized pedestrian advice *on-demand recommendation* using data from different sources such as crowdsourcing data, open data, historical/batch data, real-time data, etc. (Chen et al. 2021). Furthermore, the auditory interface should be designed in a way that it can improve older people *awareness of adaptations* thereby providing a medium to preview, check, discard, override, revert, save, recover, and test any possible adaptations (Gonçalves et al. 2021). Older people should be provided with easy, explicit, and clear *guidance during setting up and future troubleshooting* of the AI-based voice-assistants installed in the device (Chen et al. 2021). To enhance the service design of AI-based voice-assistants suitable for older people, designers should address *low system performance* by changing the functionalities provided by the designed systems, not changing how users utilize the designed system (Chen et al. 2021).

Research suggested that *voice-assistants should be multimodal*, precisely incorporating non-verbal communications. Multi-modality is an important design requirement to be considered in the development of auditory interface for systems (Abdolrahmani et al. 2021). The voice-assistants should have *easy access* that provides help to users (Wedberg and Dalgren 2021), from a design perspective, for first time users the application should have some sort of introduction or short user guide, that is intuitive and user friendly to understand. Nonetheless, it is crucial to mention that these requirements will vary depending on the older user's technological knowledge, difficulties, and background (Wedberg and Dalgren 2021). Since older people would prefer conversing with a real person rather than interacting with a computer-generated voice in case of an emergency. It will be more beneficial if the AI-based voice-assistants *can recognize the state of the user* (older people), based on their voice in case of a fall, injury, or accident when walking or using public transportation without the person requiring screaming or prompting the AI-based voice-assistants to call the emergency center. Thus, the system should enable connection with family members, care giver, or emergency services in case of fall, injury, or accident (Wedberg and Dalgren 2021). Also, the design of AI-based voice-assistants that provide a safe mobility and walkability service should be *similar to other digital platforms* available for easy uptake and use.

**4.2.2.2 Functional requirements for older people centric voice-assistants** Grounded on the usability evaluation for design of artifacts this section identifies the functional requirements to be considered in developing AI-based voice-assistants for older people. Where, the functional requirements capture the design requirement of the designed product from the lens of the user (older people). Due to changing needs and requirements of end users in the society individuals such as older people are the ones determining the usefulness of designed and developed digital systems. Grounded on the literature (Dix et al., 2003; Mayordomo-Martínez et al. 2019; Wedberg and Dalgren 2021), on usability evaluation, the design of AI-based voice-assistants should provide the following requirements to be useful to the aging population as seen in Table 2.

#### 4.2.3 Techno-social inhibitors influencing use of AI-based voice-assistants

*This section aims to address RQ 2: Which techno–social factors may influence the use of AI-based voice-assistants by older people?* Based on the secondary data the technological and social factors that may influence the use of AI-based voice-assistants by older people are discussed in this section. Due to the fact that this study investigates a vulnerable group in the society there is need to investigate the technological and social challenges that influence the adoption of AI-based voice-assistants by older people. The identified technological and social inhibitors are captured in Fig. 8 below.

Figure 8 presents the techno–social challenges that influence the adoption of AI-based voice-assistants by older people. Each of the technological and social inhibitors are discussed below.

**4.2.3.1 Technological inhibitors that influence older people use of voice-assistants** Findings from da Paixão Pinto et al. (2021) reported that older people were apprehensive toward their *loss of privacy and autonomy* which stems from them providing personal data such as health information to voice-assistants. As findings from the literature stated that many older people were not at ease with devices listening to their personal conversations and they are not sure as to where their data is being used or where it could be sent to for data processing (Gudala et al. 2022). Thus, *privacy* concern was mentioned as a perceived inhibitor that limits the use of voice-assistants in the literature (Chen et al. 2021). Furthermore, the *occurrence of technical errors* faced by older people will increase their resistance toward the use of AI-based voice-assistants. Hence, designers should focus on developing applications that do not require much training or technical knowhow to be used (Bokolo 2023a). Also, the effort required to setting up voice-assistants is important and the capability of these systems to effectively *manage any operational failure* is a factor that impacts the future uptake of AI-based voice-assistants. Moreover, the technology should *support contextual awareness* of older people so that they can better connect to their surroundings to perform the right action (i.e., safe mobility and walkability). Findings from the literature suggested that older people were interested and welcomed the use of technologies to improve their capability to *manage their surroundings* particularly using their voice (i.e., actuation via voice, specifically for those with slight mobility impairment, as

**Table 2** Functional requirements of voice-assistants designed for older people

| Functional requirements | Description |
|---|---|
| Informativeness | The information provided by the system should be positively associated with safe mobility and walkability for older people |
| Cognitiveness | It is expected that the cognitive skills of older uses of the system will impact more toward successfully accomplishing task such as mitigation of falls, injuries, and accidents over the knowledge of older pedestrians |
| Ease of use | The designed system should be less complex such that older people can navigate the AI-based voice-assistants with ease as compared other similar applications |
| Texts captions | The length of the text/sentence should be directly proportional to the quotient of informativeness |
| Integration | The degree to which the use of AI-based voice-assistants can be deployed with existing mobility and walkability aids for older people. When integrating the notion of cognitiveness (reasoning, thinking, or remembering), alongside that of usability, improvement in the expediency quotient should be anticipated |
| Predictability | The AI-based voice-assistants should help older people to ascertain the outcome of future action to improve safe mobility and walkability based on previous interaction or historical data |
| Synthesizability | The system should support older people to evaluate the result of past interaction based on their current condition to reduce any possibility of falls, injuries, and accidents |
| Understandable | When designing voice-assistants, it is important to understand how conversation design can create better experiences that enable the system to communicate like humans. The system should be designed based on how older people actually converse and not how the designer wants them to talk |
| Responsiveness | Involves how individuals perceives the speed of interaction with the AI-based voice-assistant. The voice communication should be clear and brief, and there should be options for follow-up questions if needed by older people. Also, it is important for the voice-assistants not to delay answers to questions as this will make the conversation feel more like a human–human dialogue |
| Sociability | In developing voice-assistant, it is challenging to design right answers, nonetheless, the most important aspect is responding only to what is asked by replying to the most important questions, such as "Yes" or "No" and then following-up with other details if needed. Most older people prefer a kind way to end the conversation, so it is necessary to make the voice-assistant to be polite when ending a conversation |
| Familiarity | This refers to the degree to which older users experience and knowledge in using other technologies can be harnessed when they interact with the designed AI-based voice-assistants |
| Generalizability | The system should help to extend older users knowledge pertaining to the use and interaction of voice-assistants based applications used in different domains such as in healthcare |
| Consistency | There should be similarity in input–output behavior occurring during use of the system for safe mobility as well as for walkability and wayfinding |
| Dialog initiative | The system should provide freedom of use to older people and limit artificial obstruction or constraints that arise from the input dialog insisted by the system |
| Multi-threading | The system should possess the capability to support multiple user interaction when in use such that older people can perform several tasks concurrently |
| Task migratability | This involves that capability of the system to transfer control for the completion of a particular task such as wayfinding such that the task can either be internalized by the individual or the system or shared among them |
| Substitutivity | Involves the system supporting comparable values of input and output to be arbitrarily swapped for each other |
| Customizability | Concerns modifiability of the auditory interface/user interface permissible to the user and the system |
| Observability | Capability of older user to assess the internal condition of the system based on its perceivable information represented |
| Recoverability | Ability of individuals to perform corrective actions once potential error has been identified |
| Task conformance | The extent to which the AI-based voice-assistant services facilitates all of the mobility and walkability related tasks older people intends to perform, and in the way that older users understand these actions |

this functionality will help them reduce use of their limb needed to navigate the control panels of their mobility aids) (Pfeifer-Chomiczewska 2023).

AI-based voice-assistants can support to achieve *consistent monitoring* situations that might lead to fatal dangers (e.g., detections of accident-prone pedestrian areas and giving directions during extreme weather conditions to avoid falls, injuries, and accidents). Similarly, it is suggested for designers to explore inclusion of visible input functionality such as *screen-based* to complement the auditory interface input (Pradhan et al. 2020). Thus, the *input data format* of voice-assistants is a significant feature to be considered especially for older people with physical impairment. To manage *error recovery* for a seamless conversation between the user and AI-based voice-assistants in case of system error when the application fails to execute a requested task (e.g., provide answer to a question), the system should provide more detailed feedback

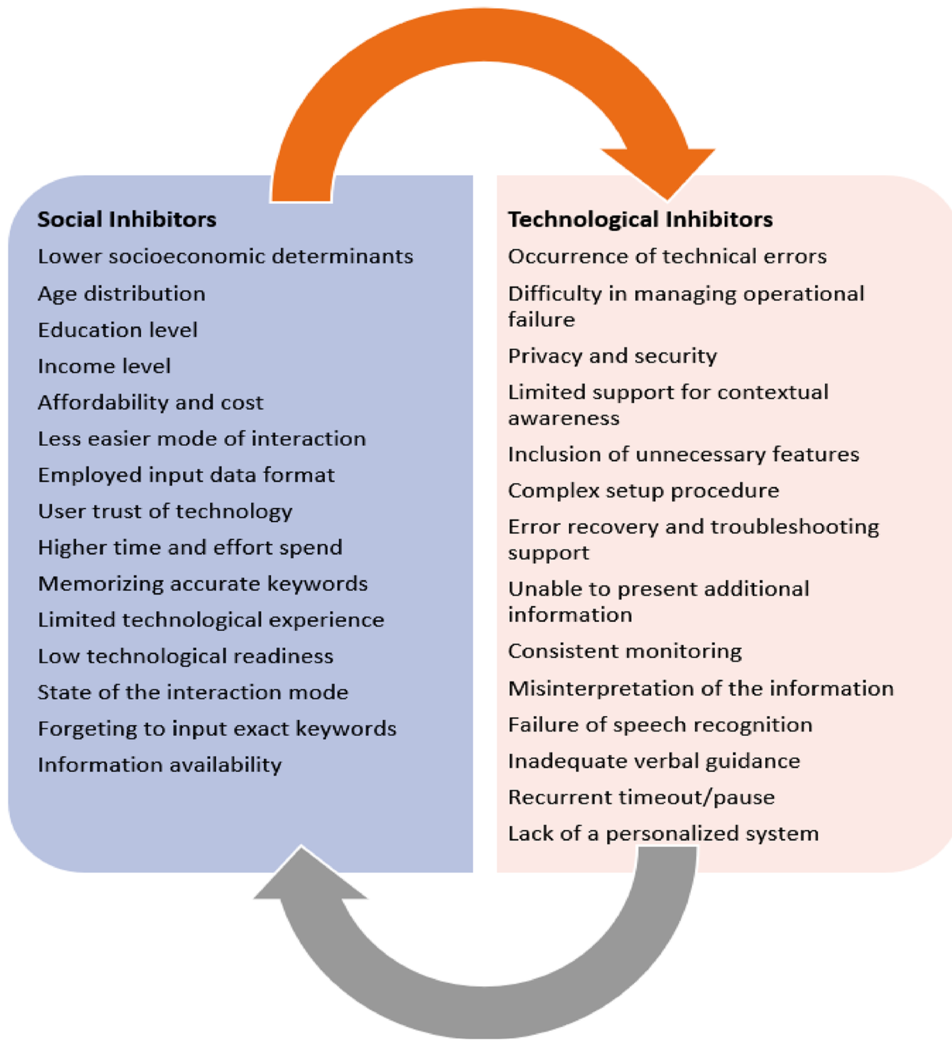


**Fig. 8** Techno-social challenges that inhibits older people use of AI-based voice-assistants

that can *support troubleshooting* (for example differentiating between inadequate knowledge of voice-assistants as opposed to voice-assistants error due to not understanding the individual or due to existing background noise) (Pradhan et al. 2020). It is also imperative to understand what and how to *present additional information* needed to operate these voice-assistants based devices to older people particularly during the device setup and error troubleshooting process (Chen et al. 2021).

An effective interaction requires digital technologies to understand end user's queries, and vice versa. Unclear output information happens when end users cannot get the anticipated information, resulting to failures to perform the needed task based on the application's output. Hence, *misinterpretation of the information* provided by digital technologies has been considered as a challenge that impacts use of technologies by the aging individuals. Findings from Chen et al. (2021) outlined how voice-assistants cannot understand user's intents. This has resulted to setbacks that limits the use of these technologies due to *failure of speech recognition* even for individuals who are native English speakers. Findings from prior studies highlighted that it is challenging to achieve 100% robust and reliable speech recognition system, yet significant for aging populations (Chen et al. 2021). A design option that can lessen misinterpretations and ambiguous information is to design AI-based voice-assistants that are basically auditable interface and not voice-only interfaces, where alternative input–output functionalities, such as touch screen, is provided to receive more clear input. This is supported by evidence from Chattaraman et al. (2019), where the authors mentioned that the use of voice-assistants that provides *verbal guidance* to older adults improves the self-efficacy for older people when they carry out their activities.

As presently most speech recognition system *require complex setup procedure*, which mostly involves the integration of additional systems for example evidence from the literature suggested that in setting up of speaker and to finalize the authentication and setup the network individuals after which users need to download and install the Alexa App on their smartphones. The process to be carried out during the setup process will often become confusing especially to older people above 65 years. This results to older people often asking for assistance from their family members. For older people living alone, not understanding these set up procedures might cause them to completely abort the setup of the technology. Also, findings from interview reported that participants are faced with complicated and inefficient interaction while using GUI-based systems by older adults. This has led to older people sticking to more conventional approaches like using pen and paper method to keep record of their daily health routines (Pradhan et al. 2020).

The inclusion of *unnecessary features* into AI-based voice-assistants would make the application more cumbersome for older people, which would result to similar inefficiencies and frustrations, likely limiting the successful adoption of AI-based voice-assistants in the aging populations (Chen et al. 2021). A usability challenge faces by older people when using voice-assistants was recurrent *timeouts.* Either older participants were not able to completely input their proposed request on time or they mistakenly entered unintentional words into their query. Older people may substantially benefit from a setting that inhibits searches from automatically triggering a *timeout/pause.* For instance, when sending a text message via Google Assistant, the system will prompt the user to input the message and later ask the user to confirm or edit the entered texts before sending the message (Ziman and Walsh 2018). The study by Chen et al. (2021) stressed the significance of providing a *personalized system*, when designers develop data-driven applications for older people. As noted by author in their providers advocated considering the difference between the age of 65–74, 75 and older since those in their eighties and above may already start having problems with memory and ability. Thus, the design of AI-based voice-assistants cannot be tailored as a one-size-fits-all application.

**4.2.3.2 Social inhibitors that influence older people use of voice-assistants** Overall, older people with backgrounds from lower *socioeconomic* and those who are 75 and older might have problems with digital technologies (Gudala et al. 2022). Also, the *affordability and cost* of acquiring devices where AI-based voice-assistants can be implemented could be challenging for older people from *lower socioeconomic*. Conversely, this depends on the *technological readiness* of the age group of older people as those between 65–74, 75 and older may face technical difficulty whereas those between the age of 55–64 may have some experience with technology and thus requires a much more attractive and elaborate solutions (Chattaraman et al. 2019). Accordingly, the *technological experience* of the older users must be considered when providing AI-based voice-assistants that offers personalized safe mobility and walkability support. As the degree of personalizing behavior for reducing risk of injuries, falls and accidents may lead to increased uptake and acceptance of the technology (da Paixão Pinto et al. 2021). Hence, designing an AI-based voice-assistants suitable for the aging population in the society is a challenge (Chattaraman et al. 2019). As anticipated, *the easier the interaction mode*, the greater the acceptance and use of the voice-assistant system.

Thus, AI-based voice-assistants that stimulate physical activities such as walking and cognitive skills such as wayfinding is recommended in the literature. As such AI-based voice-assistants can be *customized,* via *adaptation* of information, suggestions, and feedback based on older users' preference (da Paixão Pinto et al. 2021). Evidence from the literature argued that issues associated with *remembering certain keywords* for using some features in the AI-based voice-assistants was a challenge for many older participants, stressing concerns about the cognitive accessibility of this digital technology. In comparison to conventional devices, this challenge might not occur as often, since the input feature is visible to older user (Pradhan et al. 2020). In addition, instead of assuming that older users remember the accurate keywords, designers of voice-assistants should employ heuristics of checking older user input, i.e., if individuals *forget to input "exact keywords*", the voice-assistant should predict possible input request and confirm it from the individuals. Likewise, contextual cues (such as the current and past location of the user, recently inputted requests from the user, most visited location, etc.), can be incorporated into the dialogue design where possible (Pradhan et al. 2020). Other inhibitors include *user trust* in technology that talks back to them.

Although results from Gudala et al. (2022) stated that many older people are using technologies, such as smartphones, computers, and some even used voice-based technologies such as Siri or Alexa in their day-to-day activities. This suggest that a few older people *trust* digital technologies and have no hesitation to use voice-assistants and share their data while using it. There is need to design AI-based voice-assistants that does not require older users to *spend time and effort in using* this technology to improve safe mobility and walkability. Thereby, allows for a better design of such micro-interactive task and will help in particular by reducing the access time required for older people to use this technology (Chen et al. 2021). Another challenge to be met is that older people have little experience in using ticket machines and they are concern with diverse ways of paying (Ståhl et al. 2008). Also, *available information provided* by the voice-assistant on mobility modes is also a key factor that influences older peoples' use of public transportation (Bokolo 2023b). *Available mobility information* of new routes, new accessible timetables, or buses, and bus stops. This is because information availability leads to older passengers travelling more, while limited information resulted to a decline in the number of travelers. Thus, voice-assistants should be able to provide information such as timetables, posters at bus stops, and information on departure times and connections (Levin et al. 2012).

Findings from Gudala et al. (2022) maintained the *age distribution* of older people influence their acceptance and uptake of AI-based voice-assistants as most distribution of people particularly between the age of 55–64, are more tech-savvy and use to technologies as compared to those within the age distribution of 65–74, 75 and older. Gudala et al. (2022) stated that even though there has been an increase in technology adoption among older people in general, the uptake and use declines once older people are above the age of 70 years as compared to those within the ages of 65–69 years. In addition, it was reported that the use of certain technologies, for example smartphones, was seen to be greater among well-educated, affluent, and younger–older populations. Also, there was also a deviation in the type of technology that is being used by older people aged > 75 as compared to those who are younger between the age of 55–64, 65–74. Overall, the findings indicated that there might be variances in the adoption rates of voice-assistants based on older people age and other associated socioeconomic factors, such as education and income levels (Gudala et al. 2022).

#### 4.2.4 AI-based voice-assistants to mitigate falls, injuries, and accidents by older people

Presently the design and development of voice-assistants has mostly focused on one communication modality, such as speech or text. Nevertheless, the use of other user centered modalities (for instance use of graphical based elements or visual text, physical buttons/touchscreen), in the design tailored for older people may improve the mobility and walkability needs of the aging population (Abdolrahmani et al. 2021). As such provision of a *multimodal output* could be valuable especially for older people with sensory impairment. AI-based voice-assistants needs to appropriately understand the safe mobility and walkability needs of older people and thereafter provide mechanism to mitigate the risk of falls, injuries, and accidents. Furthermore, researchers such as Abdolrahmani et al. (2021) proposed incorporating multiple modalities in an accessible medium which can contribute to achieve better interactions with voice-assistants, specifically in handheld devices. This was supported in their findings, where eyes/hands-free interaction with voice-assistants employed to support daily travel offered immediate access to sighted and blind travelers who needed information during different phases of the journey (Abdolrahmani et al. 2021). Though, there are challenges that may influence the effectiveness of these interactions, such as the cognitive load originating from the incessant spoken output of the voice-assistants while older people are walking in urban environments (mainly challenging for older people with vision impairment or legally blind who require their sense of hearing to recognize their current location or environmental awareness by listening to sounds) (Abdolrahmani et al. 2021).

The use of voice-assistants for this group of older people may results to speech/voice recognition problems and hearing difficulties in noisy environments. To address this constraint, researchers such as Abdolrahmani et al. (2021) advocated for individuals to choose *from different modalities* such as vibrations, earcons, or spoken output to receive notifications/responses offered by the voice-assistants (for example when users are heading toward a wrong route, walking pass a favorite Point of Interest (PoI), accessing a ride-sharing service). Overall, the integration of voice interactions with additional services and modalities in a meaningful way to facilitate diverse needs of older people in urban contexts will improve the usability of AI-based voice-assistants while providing a more natural means of communication (Abdolrahmani et al. 2021). Furthermore, to improve wayfinding to older people when they go for walk the contents of the voice-assistants must provide *clear, easy, and understandable information*, which is compatible across different device screen. When providing basic information, it is important to provide older people with the *possibility of modifying the information* based on the user's accessibility preference and user requirements. Image information can be included to be supplemented by description of the information, which is to be understandable, irrespective of the user's knowledge, experience, or current level of concentration (Peraković et al. 2015). It is encouraged to disable procedures that create information that require the full concentration of the user. The operation and use of the voice-assistants should not require much mental or physical effort from the user.

The AI-based voice-assistants can provide *real-time traveler information* for older people when they use public transportation for their mobility needs. The real-time service can inform the user using voice or audio information regarding any changes based on their pre-planned route when they go for walking. For instance, if there is construction or road closure along the pedestrian crossing and if there is a chance of not being able to cross, the individual receives information on this, and the voice-assistant provides suggestions about different routes for safe walking (Peraković et al. 2015). To improve safe mobility and walkability for older people the voice-assistant needs to be *adaptable scalable, and flexible*. To achieve this previously validated machine learning models used in similar contexts for other people in the past can be adjusted to the current needs of older people. The employed machine learning models should also be instantiated and adapted to reflect new features and interactions evolving from the use of voice-assistant in handheld devices for mobility and walkability purposes (Sochor 2015). Older people should evaluate and practice with the AI-based voice-assistants in a real environments and contexts, thus ensuring safe mobility and walkability. The user interfaces and auditory interface should be intuitive to support the best possible interaction mode for older people. To promote inclusive design older people with visual disabilities, the interfaces can be designed in ways that aids information to be perceive. When the GUI includes text (in labels and menus), it is recommended to use sans serif fonts, as the resolution of the device screens are typically lower than paper.

This makes reading from the screen less exhausting and easier for older people. A contrasting color (such as black/white or blue/yellow combinations), and clear interlining spacing can also be considered. Iconic photographic pictures with good contrast with the background color should be used (Sochor 2015). Audio prompts can also be included so older people can build a mental model of the digital environment, thus improving their interaction with the voice-assistants. To improve interaction with the voice-assistant diverse ways of navigating the system should be provided. The *voice-assistant should use excellent quality and easily understandable audio*. Audio clues such as non-spoken sounds can be used as they are easier to listen to as compared to verbal audio cues, since they do not distract older pedestrians during navigation. Iconic sounds occasionally referred to as earcons are applicable to convey navigation related information, whether it is specific, general, or quantitative (Sochor 2015). Mobility related *information should always be available* to older people, and they should be able to listen to important messages. The design of the voice-assistants should support asynchronous feature when the system required to provide auditory information without being spoken back to and the system should be able to repeat important messages. Navigational recommendations provided for safe walkability should be *simple and clear contextualized information* since older people may be distracted as they walk within the build environment. The AI-based voice-assistants should provide contextualized information about the orientation and position of users, their destinations, landmarks, and obstacles to avoid. The system should be able to adapt to user's environment by adequately providing hints that fits the mobility and walkability needs and experience of the current older user (Sochor 2015).

However, the customization should be executed by the user by adapting the voice-assistant and providing the system with information which is used by the machine learning to learn and plan and recommend present and future mobility and walkability personalized to the user needs (Sochor 2015). The device in which the AI-based voice-assistants is installed and deployed to be used by older people should be portable so that it can be comfortably carried in their hand or in their pocket. Overall, when older people use voice-assistants for route navigation it should not *affect their primary walking aid* utilized such as walking canes, rollators walking aid users, and wheelchairs, electric mobility scooter, etc. AI-based voice-assistants should *consume less battery*, such that older people can use it to provide uninterrupted mobility services for long distant travel. AI-based voice-assistants should enable older people to carryout straightforward service-booking, *provide information* to older people related to walking times to and from bus stops, trip time, frequency of public transport service (e.g., city bus), changing or connection between different forms of transport and availability of shelters at bus stations/stops. Information related to availability of seat on public transport service such as buses for older people (Levin et al. 2012). If possible in designing AI-based voice-assistants there is need to reuse existing devices and infrastructure that provides information needed for safe navigation. This implies that older people should be able to autonomously navigate urban environment e.g., taking the stairs or through narrow hallways (Sochor 2015).

#### 4.2.5 Designed architectural model

*To address RQ3: what AI techniques are suitable to design an architectural model for a voice-assistants that provide information to older people for safe mobility and walkability?* This section presents the designed architectural model for the voice-assistants as seen in Fig. 9 to be used to implement the AI-based voice-assistants. The designed architectural model captures the *AI techniques (machine learning, NLP, and speech recognition),* needed to achieve a user-centric experience that improves mobility and walkability safety toward reducing falls, injuries, and accidents by older people. Thus, the architectural model mainly comprises of the *three fundamental AI techniques* (machine learning, natural language processing, and human–computer interaction components (*speech recognition)*), needed to deploy a voice-assistant system. The overall architectural components are designed based on prior studies that developed architectures (Tsiourti et al. 2016a; Su et al. 2017; Wiratunga et al. 2020; de Arriba-Pérez et al. 2022). The designed architectural model is presented in Fig. 9, and description of each of the AI techniques are subsequently discussed.

**4.2.5.1 Machine learning** In this study *machine learning* is included as seen in the architectural model to support older people plan their journey and walking. Machine learning modules enable predictions and personalization based on the available data as seen in Fig. 9, to provide

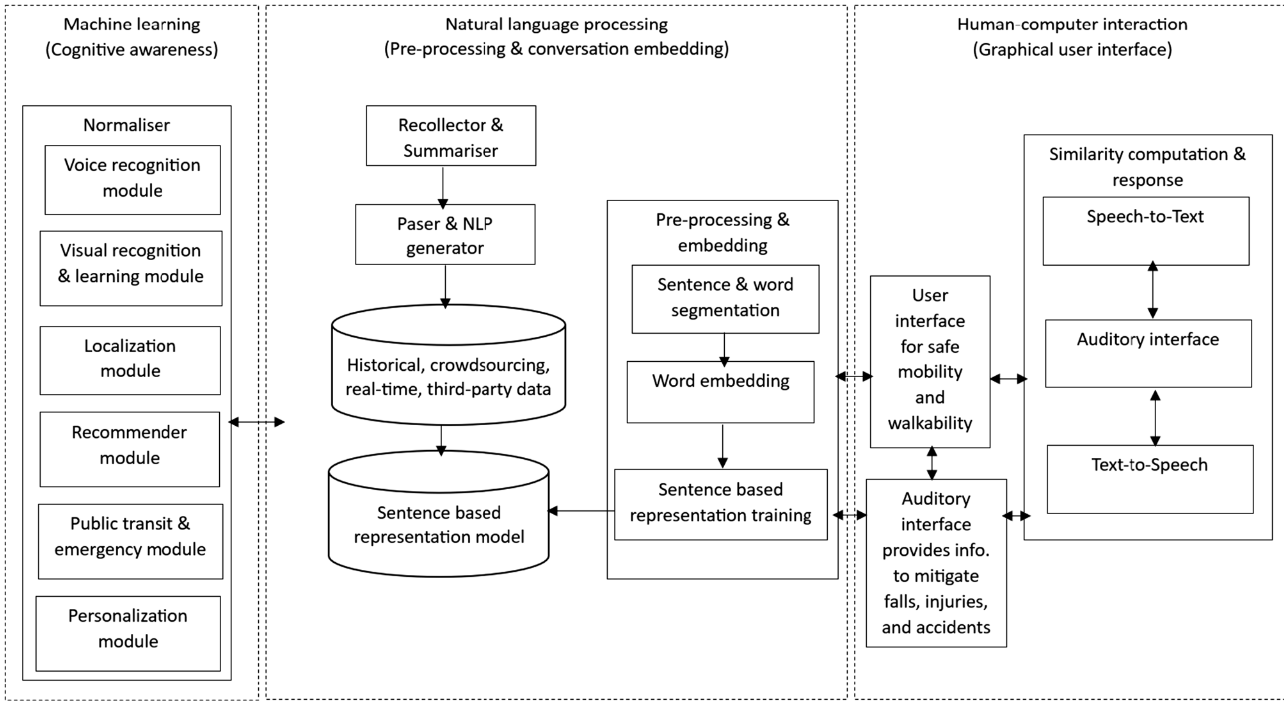


**Fig. 9** Designed architectural model for developing the AI-based voice-assistants

suggestions to reduce falls, injuries, and accidents by older people. Essentially, rules are employed to provide recommendations, which describe a change in state of the built environment such as change in broken sidewalks, curbs without cuts, busy roads with no sidewalks, high elevations, construction closures, and landmarks will be used with publicly available data. Older people will also provide and save personal information relevant to their mobility needs (e.g., age distribution, endurance level, ability to navigate uneven terrain, use of any existing mobility support, disabilities if any (physical, on wheelchair or with legal blindness/vision impairment, sensory, and learning impairment, etc.).

These data (historical, crowdsourcing, real-time data) can be collected from municipalities, individuals, and devices. Using machine learning models data on the road capabilities, elevation changes, road slope, weather (Open Weather Map), route nodes, traffic situation, public transit, multimodal transit, accessibility, rest opportunities, and facilities (Darko et al. 2022), is provided for personalized route guidance for older people in their handheld devices for safe mobility and walkability once they input their preferred destination to the voice-assistants. The goal is to provide the voice-assistants with functionality to compute predictions and the consequent rules, using different data to describe the safe mobility and walkability needs for older people. Particularly, machine learning module will produce a set of understandable and readable "*if–then*" conversation, which is easily to be explainable and follow a dialogue pattern similar to human conversation (Valtolina and Marchionna 2021). This will help to suggest mobility modes based on older people mobility needs and also able to check for anomalous situations that may lead falls, injuries, and accidents when older people walk within and across cites. Thereby providing suggestions to older people on how they can avoid these risks.

**4.2.5.2 Natural language processing** Usually, a voice-assistants consists of automatic speech recognition and natural language processing. The NLP comprises of pre-processing and conversation embedding, which is based on paser, and NLP generator, recollector and summarizer, sentence-based representation model/training as well as sentence and word segmentation, and word embedding. As shown in Fig. 9 Microsoft's native text-to-speech engine or Google Voice Android Software Development Kit (SDK) can be employed for text-to-speech and speech-to-text conversion. Thus, Google Voice Android Software Development Kit (SDK) is to be used as employed in prior studies (Tsiourti et al. 2016a), to convert text into natural spoken speech and vice versa. In addition to the natural speech communication support by NLP, older people can issue commands via *human–computer interaction* to the voice-assistants using buttons and features on the graphical user interface (GUI).

**4.2.5.3 Human–computer interaction (speech recognition)** Older people will interact with the voice-assistants using a multimodal interface including a touch-based GUI and automatic voice recognition. Similarly, analogous with prior studies (de Arriba-Pérez et al. 2021), the AI-based voice-assistants can be automatically activated using audio sensors via the microphone of the device through voice commands. Google Voice Android SDK can be used to perform speech-to-text and text-to-speech conversions (https://developer.android.com/reference/android/speech/SpeechRecognizer). Similar to prior studies (Park et al. 2021), to support wayfinding for older people the prototype will provide visual recognition capabilities to intelligently recognize tracks along edges of sidewalks, and traffic warning symbols and signs via machine learning algorithm. *In addition, the GUI is expected to be designed based on the user-centered design strategies taking into account the service design and functional requirements of voice-assistants designed for older people (as specified in* Sect. 4.2.2 *and* Table 2*), and feedback from older people representatives.*

The final prototype design of the GUI will be limited to necessary functions (to reduce falls, injuries, and accidents), as suggested in the literature (Tsiourti et al. 2016a), that provides clear feedback to the user on improve safe mobility and walkability. This design will enable a touch-based auditory interface. The AI-based voice-assistant is to be developed to provide personalized real-time information to reduce falls, injuries, and accidents by older people in both Android and iOS devices. Android Studio and Swift will be used in Java programming and SQL databases as database management including local and Firebase Cloud Firestore for crowdsourcing abilities (Owens and Miller 2022). Interactive Maps for safe routing and navigation is to be provided sourced from open-source platforms such as Mapbox as suggested in the literature (Park et al. 2021; Darko et al. 2022). The graphic appearance will comprise of large icon sizes and capitalized font, clear and simple font, strong color contrast with full-screen mode, and enabled volume settings (de Arriba-Pérez et al. 2021).

## 5 Discussion and implications

### 5.1 Discussion

Presently, voice-assistants such as Microsoft's Cortana, Google Assistant, Amazon Alexa, Apple Siri, etc. are being deployed for older people to provide reminders, entertainment, control of home devices, companionship, and emergency communication (O'Brien et al. 2020). The significant uptake of voice-assistants provides potential benefits to provide recommendations for safe mobility and walkability of older people. These voice-assistants can enable personalizing to older people by providing assistance, reminder, monitoring, and guide to execute mobility and walkability activities (da Paixão Pinto et al. 2021). Results from O'Brien et al. (2020) suggested that voice-assistants could be helpful to provide cognitive, functional, and social motivation to homebound older people and support healthy aging. Findings from Ziman and Walsh (2018) indicated that multiple participants (mostly older people) expressed dissatisfaction as they struggle with the device keyboard to provide input but were satisfied when they use voice input as compared to typing words via keyboards (Ziman and Walsh 2018; Wiratunga et al. 2020). Thus, findings from the literature (Gudala et al. 2022), highlighted that older people preferred voice-assistants that could mimic natural interactions.

Therefore, this study investigates how to design a user-centered AI-based voice-assistants that is able to adapt its content, functionality, personality, auditory interface, and information access to improves its communication skills to older people to reduce the risk of falls, injuries, and accidents they face when they use public transportation and when they walk within and across urban environment. Moreover, this study identifies the techno–social inhibitors that may influence the use of AI-based voice-assistants by older people to provide better solutions that can support the mobility of older people. Findings from this study presents the user-centered service design and functional requirements to be considered in developing AI-based voice-assistants suitable for older people of present and of the future. This study builds on prior studies on voice-assistants by designing a high-level architectural model to be used in developing an AI-based voice-assistants that provide user-centered real-time information to reduce falls, injuries, and accidents by older people for safe mobility and walkability. Findings from Gudala et al. (2022) highlighted that older people who are fairly younger (those in their 60 s) have had experience with technology while they worked and may have learn to use similar technologies from family members are likely to accept and use novel technologies such as voice-assistants in particular. For such older people, technology readiness, familiarity, and uptake of voice-assistants to support safe mobility and walkability would not be a major barrier.

On the contrary, for older people aged 70 years and above, especially for those who live alone technology familiarity could be low and this can act as an inhibitor to use of voice-assistants. Nevertheless, older people are a special user group in the society since they are often less acquainted with digital technology (Seiderer et al. 2020), and may not have equal access to a stable internet connection which is needed for most the functioning of the AI-based voice-assistants. Moreover, there are other techno–social inhibitors that restraint possible use of AI-based voice-assistants by older people, and in particular, security and privacy related to techno–social challenges use. For example, findings from the literature have found that older adults are concerned about voice-assistants listening in on their personal conversations and they are anxious about privacy and how voice-assistants may use their private data (Colombo-Ruano et al. 2021). Evidence from the literature suggest that such setbacks can be overcomed by making the use of voice-assistants easy and proving support with the installation and usage (Gudala et al. 2022).

## 5.2 Practical implications

Safe mobility and walkability of older people is necessary to improve the quality of life of the aging society and also to reduce falls, injuries, and accidents faced by older people especially in harsh weather conditions (winter, rainy windy, etc.) Currently, AI-based voice-assistants are becoming more popular as they allow the easiest and most natural communication with a computer system. Particularly, for older people such auditory interfaces enable interaction with assistive technologies. Regardless of the many technological advances in AI-based voice-assistant, there are fewer work conducted targeting older people as end users (de Arriba-Pérez et al. 2021). This has motivated this current study to adopt a user-centered service design approach for design of a personalized AI-based voice-assistants for the aging population. *The goal of the AI-based voice-assistants is to support pre-emptive falls, injuries, and accidents faced by older people for mitigating risk in the bult environment.* To this aim an architectural model is designed for an AI-based voice-assistant that simulates human-like behavior to provide mobility, walkability, and wayfinding guide through an auditory interface when older people walk in urban areas.

The main objective of this work is to design an architectural model for an AI-based voice-assistant that uses auditory interface, in order to support the development of an AI-based voice-assistant application suitable for older people. AI-based voice-assistants must be easy to use, low-cost, and easy to be managed by older people in their houses for travel and walking purposes aimed to supports municipalities to provide personalized real-time information to reduce falls, injuries, and accidents by older people. Specifically, the architectural model is designed to provide available and accessible public transportation services, supported by *ML, NLP, and speech recognition* which helps to automatically adapt the conversation via *human–computer interaction* to older users' toward reducing risks for improving safe mobility and walkability. This study offers important practical implications for the development of AI-based voice-assistants that will possess both text-to-speech and speech-to-text tools capabilities of converting spoken words by older users. Also, as suggested in the literature (Tsiourti et al. 2016b), older people can interact with the voice-assistants using a multimodal auditory interface that offers an automatic speech recognition and graphical touch-based user interface integrated in a simplified manner based on service design approach to ease the learning process enabling older people with different capabilities to use the voice-assistant system.

## 5.3 Theoretical implications

Among the emerging technologies available, voice-based user interfaces may hold potential for increasing safe mobility and walkability for seniors by proving personalized support to reduce falls, injuries, and accidents faced by older people. This study explores how voice-assistants can make mobility management easier and safer for older people. Specifically, this article's contribution is to discuss the benefits, barriers, and requirements of such a voice-assistants suitable for the aging population. Theoretically, this study investigates service design and functional requirements to be considered when developing AI-based voice-assistants, which are affordable for non-technical people such as older people. The main challenge is to understand which techno–social challenges such as communication characteristics, interaction strategies encourage the adoption of AI-based voice-assistants specifically for older people. Specifically, this study explores the level of acceptability by older users to use AI-based voice-assistants that can support safe mobility and walkability during their daily routines. For doing this, an architectural model is designed grounded on the literature to define some rules that are automatically triggered when specific conditions take place.

Furthermore, the AI-based voice-assistants could be connected with mobility service providers to offers flexible or special transport services for older people. It can also be connected to family members, caregivers, and emergency service department in case of falls, injuries, and accidents by older people. The AI-based voice-assistants would also promote inclusive and independent mobility as well as assisted living by reducing the manual tasks of individuals entering information by typing in their hand help devices. It provides users (family members, care givers, etc.) with a system for providing personalized real-time information to reduce falls, injuries, and accidents by the aging population using an easy and auditory interface (via speech recognition), familiar to older people. To provide help to older people the architectural model employs ML and NLP modules to make predictions and to compute guidance helpful to monitor the older people walking to avoid accident-prone areas. The main feature of the ML module is its potential of describing the reasons for the computed predictions, by calculating the smallest change to the feature values that improves the prediction. Such explanations are vital since they not only allow users to understand the conditions of older people and further ensure that caregivers and family member can trust the output of the AI-based voice-assistants.

## 6 Conclusion

This study contributes to the growing body of safe mobility in cities and communities toward vision zero and seeks to understand how AI-based voice-assistants fit into the complex techno–social environment of mobility and walkability from the perspective of vulnerable users in the society specifically older people. The primary contributions of this article include: (1) understanding which user-centered service design and functional requirements are important when implementing AI-based voice-assistants for older people; (2) identifying the techno–social factors may influence the use of AI-based voice-assistants by older people; (3) discussing which AI techniques are suitable to design an architectural model for a voice-assistants that provide information to older people for safe mobility and walkability. In addition, this study designs an architectural model for an AI-based voice-assistants that provide safe mobility, walkability, and wayfinding guide when older people walk in urban areas. A scoping review of the literature grounded on secondary data from 59 studies was adopted and descriptive analysis of the literature and content-related analysis of the literature was employed. Findings from this study provides recommendations for designing user-centered AI driven voice-assistants with the aging population in mind for reducing falls, injuries, and accidents safe mobility and walkability.

In conclusion, findings from this article offers a foundation for future work, welcoming further studies regarding measures to mitigate falls, injuries, and accidents faced by the older people. This study shows that voice-assistants has potential for the society especially for vulnerable users in the society and will be a great enabler to reduce risk and improve safety of older pedestrians. In this way, this study contributes to the UN SDG 3, Good health and well-being and 10-reduces inequalities faced in the transportation sector. By exploring the prospects with AI-based voice-assistants and how it could improve the safety mobility standards for older people. Future work plan to implement the AI-based voice-assistants based on the user-centered service design and functional requirements identified in this current study and further conduct a feasibility study that will assess the usability of AI-based voice-assistants for safe mobility and walkability activities with older people. Also, the developed AI-based voice-assistants will be integrated with Internet of Things (IoT) devices such as sensor devices that provides information to improve safe mobility. In addition, in future theoretical frameworks employed in the study area will be further explored. Lastly, qualitative (via interview), and quantitative (questionnaire) data will be collected to further validate the techno–social inhibitors identified in this study as seen in Fig. 8.

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### Declarations

**Conflict of interest** On behalf of all author(s), the corresponding author states that there is no conflict of interest.



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