Human-Centered Design Components in Spiral Model to Improve Mobility of Older Adults

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Abstract	As humans grow older, their cognitive needs change more frequently due to distal and proximal life events. Designers and developers need to come up with better designs that integrate older users' needs in a short period of time with more interaction with the users. Therefore, the positioning of human end users in the center of the design itself is not the key to the success of design artifacts while designing applications for older adults to use a smartphone as a promising tool for journey planner while using public transportation. This study analyzed the use of human-centered design (HCD) components, the spiral model, and the design for failure (DfF) approach to improve the interactions between older users and designers/developers in gathering usability needs in the concept stage and during the development of the app with short iterative cycles. To illustrate the importance of the applied approach, a case study with particular focus on older adults is presented.	

Chapter 5
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Jayden Khakure, Jari Porras, and Helinä Melkas

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5.1 Introduction

The proportion of the older age group is growing [1, 2], and it is expected that in upcoming years, many older adults in North America and Europe will travel using their own transportation (i.e., with their own private cars) [3] because of the desire to be autonomous. Ego enhancement, self-esteem, novelty, knowledge seeking, relaxation, socialization, and cultural and historical factors were cited as motivation for travel among older adults [4–6]. However, Rosenbloom and Ståhl (2003) point out, "The growing automobility of an aging population poses environmental, safety, mobility, and community design challenges to developed societies" (pp. 210). One of the possible ways to reduce the automobility of an aging population is to encourage the use of alternative modes of mobility, such as public transportation; [7–9] point out, "public transport is important to older people's quality of life,

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their sense of freedom and independence" (pp. 4334). However, journeys via public transportation require travelers to (i) get engaged in a series of high-level activities such as planning, waiting, and moving; (ii) comprehend, manipulate, and process "essential navigation artifacts"; and (iii) accommodate unexpected situations due to system failure or a user's own error [7]. Such requirements can be a major hurdle for older adults in terms of accessibility, perceptions about safety, and management of the associated informational complexity [10, 11] along with the consequent high cognitive load. Responding to these challenges is possible by meeting the older user's cognitive and physical access needs through smart technological tools, thereby enabling them to use public transportation.

Among the many existing technologies, smartphones and installed applications can be considered as promising tools that can support the effective use of graphical user interfaces (GUIs), allowing users with visual impairments to customize their phones to suit their particular needs [12]; manage mobility by providing transit information and aiding navigation [13, 14]; and improve the quality of life for older adults [15, 16]. However, in designing for older adults within public transportation information technology (IT) environments, such as real-time transit and navigational information, the requirements are not necessarily the same as those for other categories of the population [11]. A major problem is that stakeholders have little understanding of how to provide better touchscreen interface tools for older users, since the de facto standards of basic operations on touchscreen-based smartphones, which consist of tapping, dragging, and pinching, have only been adopted in the last few years [17]; how to integrate audible, haptic, and visual feedback that is responsive to older users' physical, cognitive, and mental capacities; and how to design applications for failure caused by the device, the environment, and the user's own action and supporting technology in a special context; [9, 18] state, "As the system developers target bigger markets from their economic point of view, many products do not address the requirements of specific groups of older people (e.g. those with mobility difficulties)" (pp. 4334).

This research attempted to bridge the knowledge gap by undertaking human-centered design (HCD) with the spiral model and the design for failure (DfF) methodological approach within the public transportation information technology (IT) environment using a smartphone application to support older users in managing and improving their mobility. This approach, which was validated by the case study, can help transit stakeholders to understand how smart mobile applications can meet the mobility needs of older adults by identifying and analyzing single probable points of failure based on interacting with older end users during all phases of the design and development process. Accordingly, the objectives of this research were:

- To extend the HCD design approach by using a spiral model and DfF and propose a design process for the development of applications targeted at older adults in an effort to improve HCD's usefulness to application designers and developers. Even though the results are solely based on a web and Android platform, we believe that this design and development approach can be utilized in other application development processes while working with and for older adults to enhance their quality of life.

- To illustrate the usefulness of HCD with a spiral model and DfF approach during the design process with particular focus on older adults, a web platform and smartphone-based application was developed. It lets older adult travelers prepare their personalized journey via public transportation at their convenience and then receive guidance throughout their journey.

Hence, to achieve the objective, this study aimed to answer the following research questions:

RQ1: How does an approach that uses the human-centered iterative design and development activities of application development with a spiral model and design for failure improve the usability needs of older adult users?

RQ2: What types of usability issues related to device characteristics (i.e., hardware and software) were discovered during the case study?

In the following section, we present related work, followed by the case study and our methodology to validate our approach. Following this, we present an interaction analysis framework in line with the case study, followed by the key findings, limitations, and conclusion.

5.2 Background Study

In this section, we describe previous work to understand the impact of aging on access to public transportation; technology; as well as the benefits of HCD, the spiral model, and design for failure that researchers have discussed in recent years.

Regarding the impact of aging on technology and vice versa, [19] investigated the factors that influence the use of user interfaces (UIs) among older users. Zajicek's (2001) study showed that age can impact the interaction between older users and the user interface. Further, Zajicek (2001) found that modalities such as speech interaction are useful for older users with visual impairments. However, such modalities had drawbacks for some older users in trying to follow lengthy output messages. Zajicek (2001) concluded that older users' requirements may vary during the design period due to tiredness, eyestrain, and decreasing abilities over time and designers should take older users' changing abilities into consideration during the design process. [20] attempted to understand how accuracy and performance vary between younger and older users while using the same user interface. The study involved experiments where performance was observed under three instructional sets: accuracy (i.e., users were asked to focus on accuracy only); neutrality (i.e., users were asked to focus on both speed and accuracy), and speed (i.e., users were asked to focus on speed only). They concluded that aging has a significant negative effect on performance and accuracy. [21] performed usability evaluation studies on the user interface of a mobile application targeted at older users. The study produced a set of recommendations regarding navigation, interaction, and the visual design aspects of smartphone application user interfaces.

With respect to the research on the requirements of the needs of older adults in using public transportation, [22] pointed out that due to the impacts of aging, older travelers have a variety of safety, personal security, flexibility, reliability, and comfort concerns about public transit, even if it is physically accessible. [9] conducted a study on the requirements of five different profiles/groups of older people using the public transportation. The study found that easily accessible information provision on public transport was important for all five different profiles/groups of older people but that the required content and delivery of the information varied between groups. [23] conducted a study with a sample of older citizens (75+ years) to understand their perceived travel opportunities. The study concluded that more needs to be done with regard to accessibility and usability of public transit for older people.

5.3 Methodological Approach

To be able to easily access public transportation, older adults will need to know how to manage their tools, locate transit information, and navigate more effectively with minimal cognitive needs. Therefore, when it comes to this target group of users, we believe that it is not enough for stakeholders to decide what older adults will consider an intuitive design. To gather the specific requirements for a user interface and gain its adoption by older users, we considered an approach that uses human-centered design (HCD) with a spiral model presented by Boehm [24] and design for failure to be the foundation of this methodology.

Previous studies have incorporated human-centered design (HCD) to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics and usability knowledge and techniques [25]. Kujala (2003) [26] pointed out that user involvement has positive effects if the user's role is carefully selected, especially during requirements elicitation and user satisfaction. Kujala (2003) stated that "users may not be able to communicate their precise requirements but they are able to explain their goals and how they approach their tasks" (pp. 13). Similarly, Uzor et al. (2012) [27] demonstrated the impact of older adults during the design process.

The results of their study showed that by participating in the design process, older users can reveal some of the obstacles that designers may not be familiar with, enabling them to resolve such obstacles in an early stage of the development process. Ferreira et al. (2013) [28] conducted research on lowering the high levels of nonadherence to medication in the older population by using a mobile application that puts the user at the center of the design process. The study concluded that the participation of older users from the initial phase and onward helped to generate ideas, enabling the application to be shaped according to the users' needs and capabilities through a continuous process of redesign. However, in the case of older

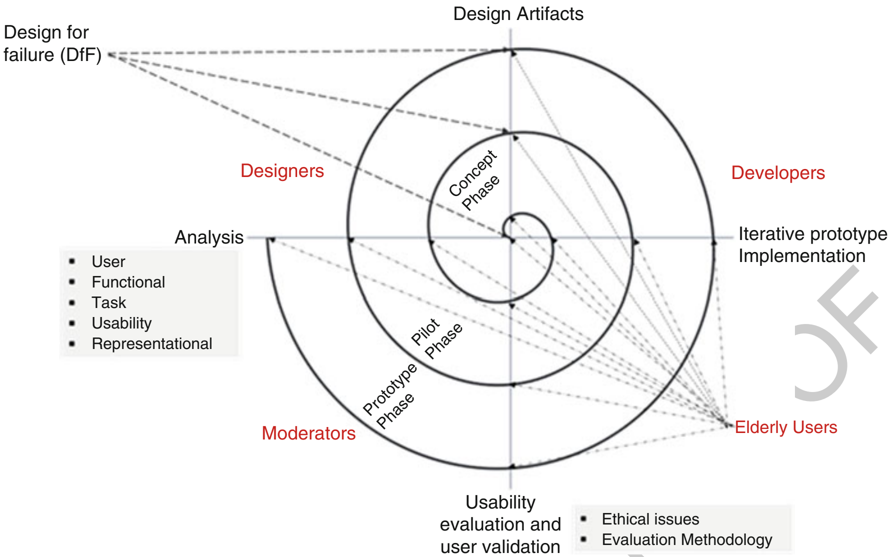

Fig. 5.1 HCD component in a spiral model with a design for failure framework

adults, the human-centered design approach has some challenges because older users "may not be able to critique a design until it is far along in the development process, which may be too late to make certain types of changes given time and cost constraints" ([29], pp. 8). Such challenges may cause tremendous risks during a project. Thus, to reduce the risk, we adopted a short iterative spiral model (i.e., three distinct phases: the concept phase, the prototype phase, and the pilot phase) and embedded HCD components (i.e., analysis, design artifacts, iterative prototype implementation, and usability evaluation and user validation) (see Fig. 5.1).

Further, technology failures are inevitable during an application's design, development, and implementation because of the complexity of the system. Similarly, human errors while using devices or applications are inevitable because of the need for a high cognitive load to learn new things. Such errors can have adverse effects on older adults' use of a system during public transit. To reduce such adverse effects, we implemented the DfF approach during the design process, which is common in software design. This study applied the DfF framework presented by Carmien (2017), meaning the system should be able to accommodate, which consists of four basic types of failure events: (i) device failure, (ii) environmentally caused failure, (iii) failure due to user action, and (iv) failure due to supporting technology in special contexts.

To help illustrate the concepts discussed and present the results of our study, we now present the proposed "Assistant" web platform and mobile application. [9] point out, "open access data provision in the transport sector has a huge potential to encourage dissemination of targeted traveler information using mobile apps with the involvement of the private sector" (pp. 4342). Therefore, the aim of this

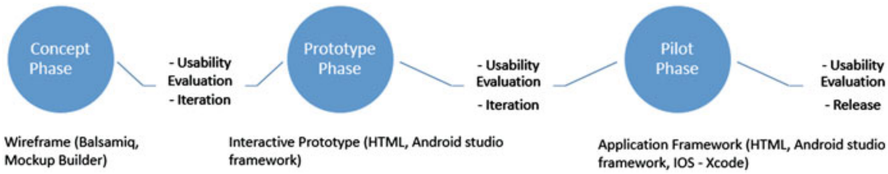

Fig. 5.2 Design iteration process

project was to develop a novel personalized and customized public transportation trip planner for older adults with or without disabilities based on the open data. The Assistant provides guidance on transfers when making multi-step journeys and assistance in getting from the vehicle to the final destination. This allows Assistant applications to accommodate expected human errors, increase accessibility, and enable effective error handling. The structure of the Assistant system comprises five main components:

- Web-based route editor platform: The backend maintains a database of public transportation information (i.e., open data) from transit providers and other customized and personalized user information for both primary and secondary users. The Assistant's web interface allows users to create a route on a map, view route calculations, and manage their profiles. Simultaneously, it monitors the users' interactions with the system, checks data for errors, and provides corrective support. Once personalized routes are created, push notification messages are sent to the users' smartphone devices (see Fig. 5.2).
- Mobile Application: The Assistant's mobile application communicates with the server asynchronously over the Internet and retrieves updated maps, schedules, and telematics data.

5.4 Analysis of Methodological Approach

The following section describes how each HCD component was incorporated with respect to the design of the Assistant application for older users within all three distinct phases (concept, pilot, and prototype).

5.4.1 Analysis

A key component of HCD is analysis, which comprises multiple levels: users, functions, tasks, and representations [30]. Rinkus et al. (2005) further explained, "The user analysis level contributes to each of the levels of functional, task, and representational analysis" (pp. 5). Since the system is designed for older users, we undertook usability as part of the components of analysis. Therefore, in our approach, the user analysis level consisted of usability, functional, task, and representational level. The following section provides a synopsis of how each requirement in this level was extracted and compiled from the focus groups of older users:

- *User analysis:* The elderly users' needs vary widely based on their physiological and psychological characteristics, which influence the adoption and acceptation of the system. This level focuses on identifying and analyzing the elderly users' physiological and psychological characteristics, which help to design a system that matches their needs, main difficulties, and limitations. Assistant, which is an "on the go" system, consists of two separate users:
  - Primary users: The older users' needs varied widely based on their physiological and psychological characteristics, which influenced the adoption and acceptance of the system. This level focused on identifying and analyzing the older users' physiological and psychological characteristics, which helped to design a system that matched their needs, main difficulties, and limitations.
  - Secondary users: Caregivers and/or relatives who may use different modules of the "on the go" system to support primary users who may or may not have reduced cognitive abilities.
- *Usability analysis:* A system that has older adults as its primary users requires early usability analysis to bridge the gap between users and devices. Usability can be defined as the ability of both primary and secondary users to interact easily with the device and its characteristics (such as physical aspects and software) when used under specified conditions to achieve specific goals [31]. The requirements obtained from a usability analysis must be tangible and can be verified and traced during development [32]. For this purpose, before starting the functional analysis, we asked some older users to answer several questions in order to collect their usability requirements. Based on the collected data and the usability principles provided by Nicolle et al. (1999) [33], ISO/IEC (2001) [36], Parhi et al. (2006) [34], and Creswell (2007) [35], the following system requirements for the Assistant were obtained: it should be simple and user friendly; the user interface (UI) should display only required functionalities; the UI should be personalized based on user preferences due to cognitive abilities; any error, warning, and other messages should be relevant and concise; the UI should be designed with more legible fonts and larger font sizes; the UI should follow all legibility guidelines relating to color contrast, lighting, font size, and so on; the application should have visual and audible instructions and haptic signals; and physical buttons should be utilized rather than touchscreens.
- *Functional analysis* is the process of identifying critical top-level domain structures, goals, and inherent properties of the work domain that are largely independent of implementation [30]. Rinkus et al. (2005) further stated that "it is more abstract than task and representational analyses because it does not involve

details of task processes and representation details" (pp. 6). The functional analysis results established the following requirements:

– Route planning (safer and effective ways to plan and compose personalized routes)
– Map accessibility annotation (provide a set of information about the essential accessibility data, such as barriers, bus/metro stops, and public facilities during route planning)
– Waypoint navigation (provide turn-by-turn guidance with waypoints for the personalized routes on smartphone devices during the trip)
– Last kilometer navigation (navigate the user from the last transit stop to the final destination using a map that consists of point-of-view maps and visual waypoint support)
– User preferences (user's personal accessibility needs and preferences are taken into account)
– Error detection and mediation (detects and accommodates human error as well as the failure of system components, e.g., going off track, stolen phone, loss of signal, success or failure of planned routes, etc.)

- *Task analysis:* Task analysis is the process of identifying the procedures and actions to be carried out and the information to be processed to achieve the users' task goals [30]. For the Assistant, we broke down the process into the following steps based on each function, identified during the functional analysis phase: high-level scenario, use case, test case, and tasks.
- *Representational analysis:* A representational analysis, which is based on the representational effect [37], refers to a phenomenon that analyzes the isomorphic restrictions that can have dramatic effects on the user's ability to accomplish the tasks. The form of a representation can influence and sometimes determine what information can be easily perceived, what processes are activated, and what can be derived from the representation [30]. During this process, suitable communication tools (e.g., smartphone devices, computer displays, and customized original component manufacturer devices) with context display interfaces for the given task for the specific set of users can improve the users' experiences overall.

Because of widespread smartphone device characteristics (i.e., physical aspects and software) in the market, the limitations placed by the smartphone device manufacturers on development platforms, and the users, tasks, usability, and functional requirements, we chose to use an Android-based Samsung smartphone. This smartphone allows users to install customized applications and has a high-resolution display, customizable widget size, fewer limitations in comparison to other OS development platforms, and device connectivity functionalities such as Bluetooth.

5.4.1.1 Summary of User Requirements

The following section summarizes the older users' requirements that need to be taken into consideration on both the mobile and web.

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Mobile: In general , the preference was text waypoints; audio of prompts was desired; request to keep smartphone out of the way to diminish the possibility of being stolen was preferred; design should take into account the role of dual glasses; Bluetooth headset was the preferred output device by many; there was a need for clarity on the waypoint page and audible prompts; fonts cannot be small; spoken control of the system was preferred; widget size and appearance were preferred; touchscreen response was preferred; switching between apps was required; and users would like orientation information on the screen.

Web: Scale of the maps and street names must be readable; maps should have the "you are here" indicator; word completion for addresses should be an option; a new terminology should not be used; font size is important; text route instructions should be included; and transfer of data from a web platform to a smartphone is required.

5.4.2 Design Artifacts

Design is essentially a search process to discover an effective solution to a problem [38], not only to provide a better user experience but also to establish the credibility of proposed or existing systems. For our case study, we defined and designed artifacts (i.e., architecture, components, modules, and user interfaces). As this analysis focuses on improving the usability needs of older users, we skipped the technical analysis and focused more on the design analysis to improve their experiences.

During the analysis, it became clear that the user interface acted as a tool for older users to interact with the system and required a particular set of features to meet all the users' cognitive needs. Our first objective was to design a user-friendly interface based on the specified requirements obtained from the analysis to maximize usability and the user's experience. Therefore, early in the design process, interviews and focus groups were held to derive a set of user requirements and different tool kits were utilized (see Fig. 5.2).

Three initial designs were prepared and presented to a focus group of older users to receive their feedback during the concept phase (see Fig. 5.3a). During the first design, online tools "Balsamiq[1]" and "Mockup Builder[2]" were used to create the wireframe. The next iteration of the design cycle was triggered to improve and introduce a new design based on users' feedback after usability evaluation where

[1] https://balsamiq.com/

[2] http://mockupbuilder.com/

Fig. 5.3 Design iterations. (**a**) Concept phase. (**b**) Prototype phase. (**c**) Pilot phase

HTML was used to create the website and Android studio framework and their libraries were utilized for smartphone application (see Fig. 5.3b). A final application was presented and tested among the older adults (see Fig. 5.3c).

5.4.3 Iterative Prototype Development and Implementation

In the concept phase, the initial stage prototype was implemented using a wireframe (see Fig. 5.4a, b) for both web and smartphone application based on the primary user's requirements, which was useful in outlining the user interface.

During prototype phase, usability protocols were implemented to gather the users' feedback on the mobile device itself. We identified a number of usability issues such as the design and physical shape of the devices in the initial mock-up, even though we followed the usability guidelines stated by Kobayashi et al.

Fig. 5.4 (**a**) Wireframe (Web). (**b**) Wireframe (Mobile)

(2011) and gathered usability requirements. After the refinement of the initial mock-up based on the new usability requirements from the users, the first prototype (see Fig. 5.5a, b) was developed, in which system functionalities such as error trapping and remediation were deployed to accommodate human error as well as the failure of system components using HTML, Android Studio framework, and its libraries. This prototype had the ability to (i) recognize path errors, (ii) use the user model to do remediation in case of error, and (iii) capture and do something about the battery running out of power or the loss of the network.

The first prototype of the Assistant smartphone application contained two different views: Navigation and Settings (see Fig. 5.5a, b). For increasing the effectiveness of real-time information delivery systems and acceptability to intervention content without deterring engagement [39], navigation views allowed the user to receive the push notification about "personalized route" generated by either primary or secondary registered user on the web client.

AQ3 Once the route is accepted, it is shown as a list (see Fig. 5.5b). Further, the application has the ability to identify the users' location, context (i.e., whether the user is walking, user is waiting for a vehicle, or user is on a vehicle), and real-time information from public transportation. For example, if the user misses the destination stop or waypoint or major delays, the application informs the user through a pop-up showing, "*You have missed your bus stop, please get off at the next stop.*" Once the user gets off from the bus stop, the Assistant application automatically recalculates the user's current location and destination and shows the alternative faster route.

The Settings view allows users to change settings for screen brightness, Bluetooth (on/off), volume (increase/decrease), and route planner (on/off). In case of emergency, users were able to call their near ones with call buttons.

After the implementation of the first prototype, we conducted new evaluation studies using three usability methods to gather the usability needs of the primary users. During the evaluation process, a user performed various tasks assigned by the evaluators. As an example, some of the findings from this prototype evaluation concerned the web and mobile user interfaces for the route planning section, such as:

- Textual information which should be put together
- The color of the button background (i.e., red)
- Unnecessary buttons
- A detailed report on how to get from place A to B
- AQ4 Wanted the system to decide the best routing for them

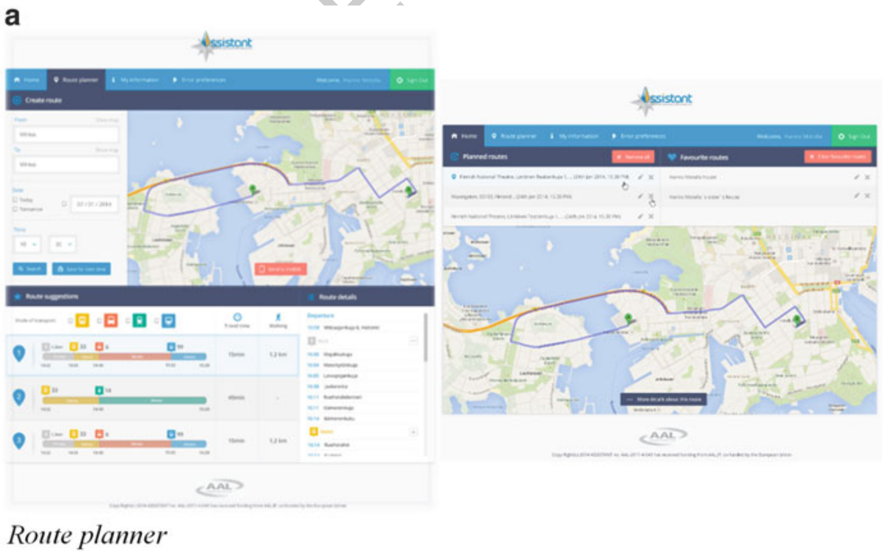
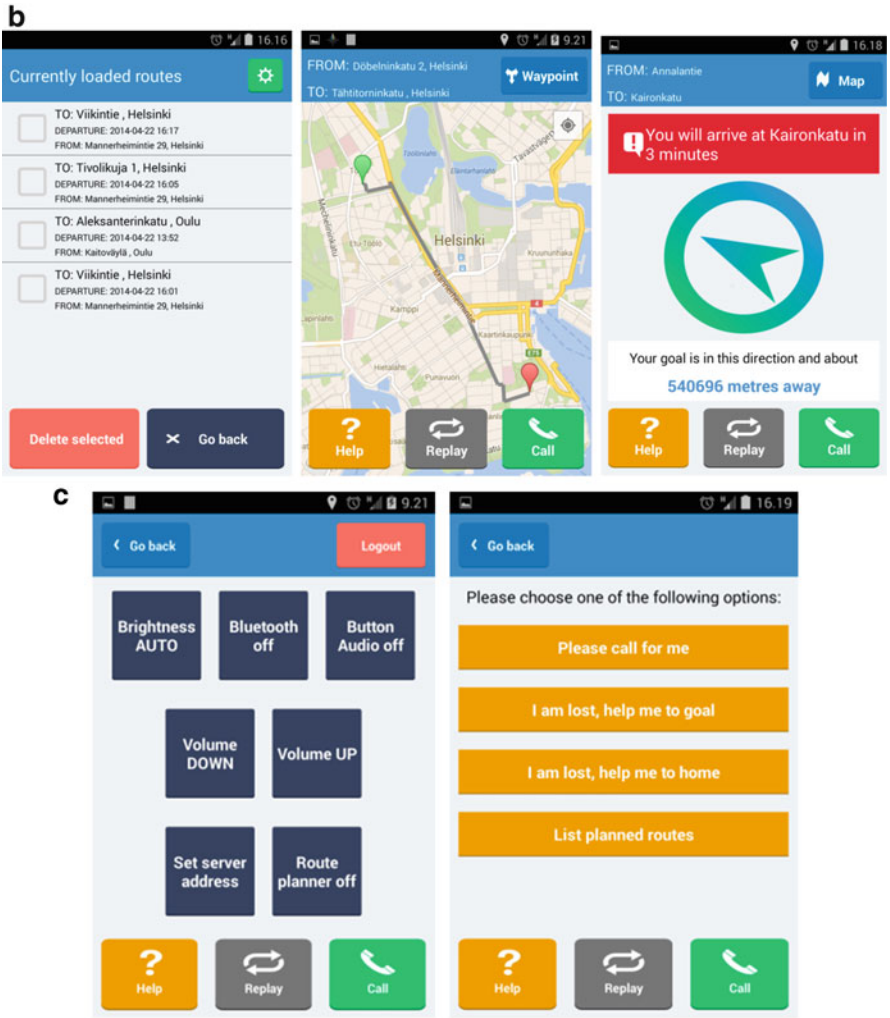


Fig. 5.5 (**a**) First prototype (Web). (**b**) First prototype (Mobile). (**c**) Prototype phase (Mobile)



Settings

Fig. 5.5 (continued)

To make the Assistant system consistent, user friendly, and usable, we refined the system based on the users' feedback from the evaluation. In the final prototype (see Fig. 5.6a, b), route planner was simplified and removed unnecessary buttons and functionalities of the Assistant system. The application was tested with both primary and secondary users to gather their feedback in real-case scenarios.

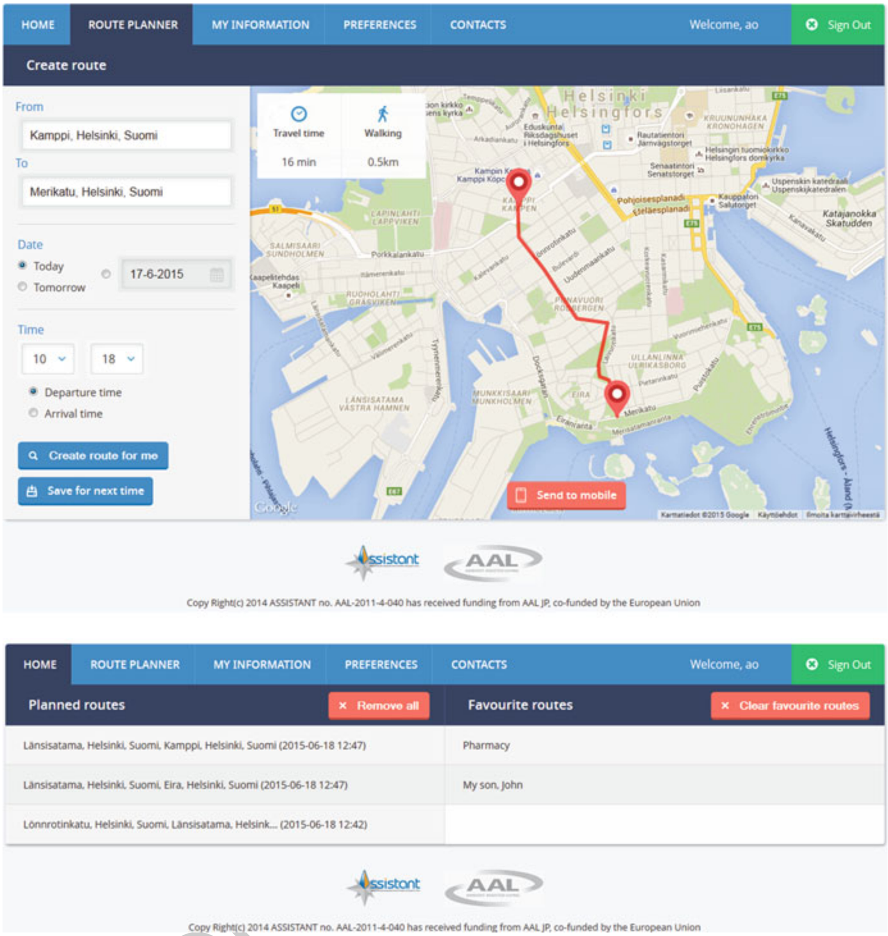


Fig. 5.6 (**a**) Final prototype (Web). (**b**) Final prototype (Mobile)

5.4.4 Usability Evaluation and User Validation

Usability evaluation methods were employed to get a general overview of the usability issues that were observed during the evaluation process. Usability is measured by the extent to which the intended goals of the use of the overall system are achieved (effectiveness); the resources that have to be expended to achieve the intended goals (efficiency); and the extent to which the user finds the overall system acceptable (satisfaction) [40].

A usability evaluation was performed on the Assistant application to understand how older users experienced each design with their cognitive abilities. To verify the acceptance of the system, older users were recruited to participate in focus

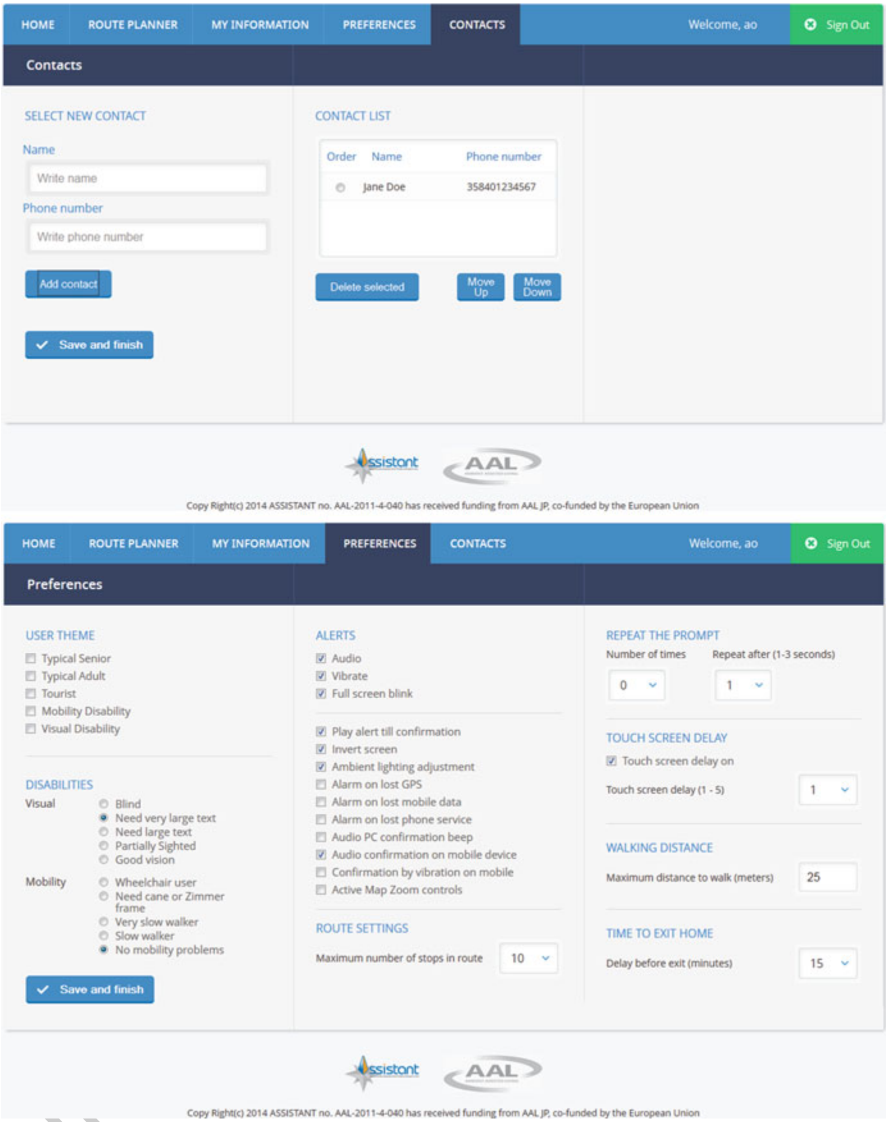


Fig. 5.6 (continued)

groups and evaluations were held in different countries: France, Spain, Austria, and Finland (see Table 5.1). Usability evaluation activities were divided into three phases: concept, prototype, and pilot. Out of three usability method classes proposed by [41], two (i.e., inquiry and inspection) were selected to conduct the usability studies. Various methods were applied because it is difficult to gather usability issues by relying on just one set of data from one specific usability method. The

Fig. 5.6 (continued)

method classes included testing, a think-aloud protocol; inspection, a heuristic evaluation; and inquiry, where focus groups, interviews, questionnaires, and diaries were applied.

Table 5.1 Summary of the focus groups, evaluation methods, number of participants, and user characteristics from each evaluation phase

Evaluation phase	No. of participants	User characteristics	Country	Evaluation method
1st	4 6 8	1:M, 3:F (65–91/years) 5:M, 1:F 4:M, 4:F	France Spain Austria	Inquiry Inspection
2nd	5 5 5	3:M, 1:F, 81,3/years 3:M, 2:F, 68,4/years 3:M, 2:F, 68,2/years	Finland Austria Spain	Inquiry Inspection
3rd	4 5 5	4:M, 0:F, 65–69, 85+ 1:M, 4:F, 71.4 1:M, 4:F, 69,8	Austria Spain Finland	Inquiry Inspection

5.5 Discussion

Generally, younger groups of users have been given more public and scientific attention than older users when it comes to technology and services [42]. In this research, we conducted a case study where we developed a novel personalized and customized public transportation trip planner for older adults with or without disabilities to show that smartphones can be important tools for them to plan trips and use public transportation more easily. Previous researchers have demonstrated that HCD is a good approach for understanding users and improving the functional and nonfunctional requirements of applications (Zimmermann and Grötzbach, 2007) [43]. However, we demonstrated that the HCD design approach is not always applicable when designing an application for a group of older users and requires another framework.

The methodology applied in this study contained four components ((i) analysis, (ii) design, (iii) iterative prototype development and implementation, and (iv) evaluation and user validation) and three phases ((i) concept, (ii) prototype, and (iii) pilot). In the concept phase, initial requirements were gathered from the older users through HCD components. The prototype phase aimed at developing the prototype and improving the design and development based on the feedback from the older users. The pilot phase processed the feedback obtained from the older users during the prototype phase. We explained that interaction is necessary for each phase of the design to enhance usability. Further, the DfF framework approach applied during each iterative cycle of the design and development phase helped the application to detect errors and fix them automatically without any adverse effects on the older users during the user evaluation phase. For example, (i) the system application automatically displays the newer timetable from the public transit system in the case of a missed connection based on the user's location and timetable; (ii) when network coverage is detected as either low or no coverage, the user's caregivers or relatives are notified automatically via the system; and (iii) when the system detects that an older user is walking away from a bus stop, a notification is provided to the user that he or she is going the wrong way and the correct direction is shown. Having components of HCD, a spiral model, and DfF can provide a tangible design within a short period based on older users' characteristics and desires, which can be constantly evaluated during all phases to receive feedback and transform failure caused by either the user or the system into a success.

As an outcome of the analysis, we discovered that despite having older adults' involvement throughout the design process with a short iterative cycle, the user could still encounter usability issues and can have an impact in terms of acceptance. For example, similar multiple usability issues were discovered at the end of the pilot phase in multiple countries with different age groups within that group. Some of these issues were (i) using compass on the Assistant application; (ii) voice commands with unclear pronunciation even though the language was in the native language of the user; (iii) using external devices such as Bluetooth headsets; (iv) inaccurate information about the route; (v) location of the buttons; (vi) calibration of the compass; (vii) size and shape of the device; (viii) battery life; (ix) weak GPS signal; (x) data connectivity; (xi) localization of the text; and (xii) auto-lock/screensaver features on the mobile devices, which stopped the users from interacting with the application during their journey. Further, this study also revealed that intermediate older users with a bit of technological knowledge appeared to have fewer usability issues compared to the novice older users who were new to the smartphone devices, which was inconsistent with the previous study by Arfaa and Wang (2014) [46]. The usability needs varied among the older adults with different user characteristics for design. For example, older adults with vision problems had different needs than those with reduced cognitive abilities. We also found out during the study that an application with too much information increases the cognitive load of older users, lowering user satisfaction.

Figure 5.7 represents the data that were analyzed with regard to the perceived use of the Assistant based on a system usability scale (SUS) during the prototype and pilot phases with the same participants. The results indicate that the usability requirements of the older adults changed over time. Our results are consistent with a previous statement from Zajicek (2001): "Requirements for a particular individual vary from time to time due to tiredness or over use of one of the senses e.g. eye strain, and as we know when people age their abilities tend to decrease over time" (pp. 64). Further, our results also showed that there are differences in SUS scores between the three countries where the evaluation was performed. One reason for this is likely to be because of differences (i) in the cultural backgrounds of the older participants, in particular, the users' perceptions of effectiveness, efficiency, and satisfaction [47]. Vatrapu and Perez-Quinones (2006) [48] also established that culture significantly affects usability results and (ii) accessibility of the public transit, in particular, where the application being used was evaluated. For example, the geographic distribution of public transit access, service frequency, transfer distance, and ticketing systems [49] in all three countries is completely different.

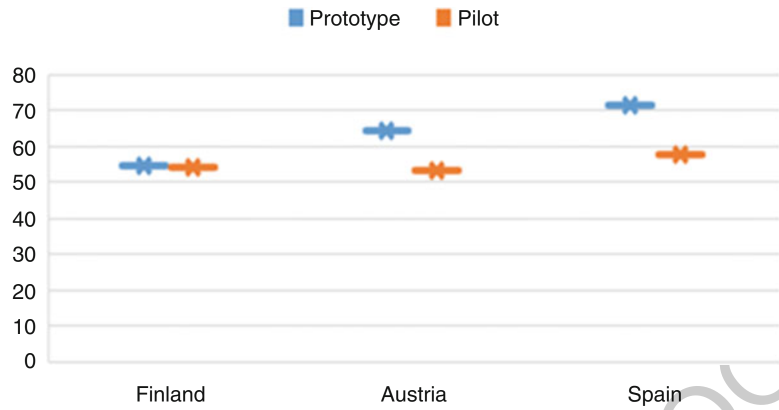


Fig. 5.7 Graphical representation of system usability scale (SUS) between the prototype and pilot phases

Although the SUS scale varied during the prototype and pilot phases, it is noteworthy that the score is still high, which clearly shows that the general perception of the older adults toward the use of the personalized mobile application for public transit was positively high.

First, in the concept phase of the user requirement analysis, the participation of the older adults (65+ years) was quite limited and did not surpass 15%; therefore, potential data bias might exist. However, in the second phase of the project, in both the pilot trials and prototype evaluations, the average age of the older participants was 72.4 years, which could alleviate the prospect of response bias. Second, since all the usability issues collected on the device characteristics (i.e., hardware and software) were based on a single Android-based smartphone device, potential bias might exist regarding the data. Further research with multiple devices is encouraged to gather more usability issues and mitigate the potential data bias.

We also observed that the satisfaction and usability needs of older users vary with aging; therefore, transit stakeholders (including designers and developers who are developing applications based on open data) must design and develop applications for older adults using the approach of HCD components, a spiral model, and DfF with even shorter iterative cycles to come up with better designs that integrate their needs in a shorter period of time than that we have applied in this study.

Certainly, the key findings from this study are beneficial to designers, application developers, researchers, and industries. In fact, the proposed methodology, which we validated with the Assistant platform and older users, can be seen as a methodology that improves design responses to the usability needs of this heterogeneous group of users.

5.6 Conclusion

In this article, we designed the "Assistant," a web platform and smartphone-based application, for older adult travelers to prepare their personalized journey via public transportation at their convenience and then receive guidance throughout their journey. We presented the framework which consists of HCD with a spiral model and DfF approach during the design process with particular focus on older adults. Additionally, we validated the framework through iterative prototype development and usability testing and final implementation within major European cities in Finland, Austria, and Spain. Our study supports that having the involvement of older adults from the beginning of the design process could initiate a better understanding of their user needs, behavior, and acceptance of transit smartphone applications; these results are in line with the previous study of Hwang and Thorn (1999) [44]. Further, such involvement could also help users feel comfortable and develop a high degree of satisfaction, motivation, and enjoyment regarding these applications' usefulness [45] .

In addition, because our study is related to the number of participants and depends on a specific operating system, the generalizability of the results may be limited, and all stakeholders including both public transportation providers and application developers should take any discussed findings as suggestions for accessibility and usability while designing applications for public transportation rather than as conclusive evidence.

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AUTHOR QUERIES

AQ1. Please check usage of "pp." in the text (e.g., "pp. 210"). Should "pp." be changed to "p."?
AQ2. The two paragraphs "In general, the preference . . . web platform to a smartphone" have been edited to maintain consistency. Please check and clarify.
AQ3. Please check if the edit to the sentence "Further, application . . . transportation" is okay.
AQ4. Please check the use of the phrase "wanted the system . . . them" for clarity.
AQ5. Please check if the edit to the sentence "therefore, transit stakeholders . . . study" is okay.
AQ6. Please provide publisher location for Ref. [35].
AQ7. Please provide page range for Refs. [39, 42]
AQ8. Please provide volume for Ref. [40].