

Conference Paper

Usability Heuristic Evaluation in AAL Ecosystems

Carlos Romeiro and Pedro Araújo

Universidade da Beira Interior

Abstract

In the past few years there has been a significant growth of the elderly population in both developing and developed countries. This event provided new economic, technical and demographic challenges to current societies in several areas and services. Among them the healthcare services can be highlighted, due to its impact in people daily lives. As a natural response an effort has been made by both the scientific and industrial community to develop alternatives, which could mitigate the current healthcare services bottlenecks and provide means in aiding and improve the end-user life quality. Through a combination of information and communication technologies specialized ecosystems have been developed, however multiple challenges arose, which compromise their adoption and acceptance among the main stakeholders, such as their autonomy, robustness, security, integration, human-computer interactions and usability. As consequence an effort has been made to deal with the technical related bottlenecks, which shifted the development process focus from the end-user to the ecosystems technological impairments. Despite there being user related issues, such as usability, which still remains to be addressed. Therefore this article focuses over the ecosystem's usability through the analysis of the process used to check the ecosystem's compliance level with the usability guidelines from Jakob Nielsen and Shneiderman; and the identification of the quantifiable parameters for each principle that could aid in the heuristics evaluation process by maximizing its objectivity improve its overall accuracy.

Keywords: Usability, Ambient assisted living, User interaction, Older people, Heuristics analysis

Corresponding Author:

Carlos Romeiro

carlos.romeiro@ubi.pt

Received: 26 November 2019

Accepted: 13 May 2020

Published: 2 June 2020

Publishing services provided by
Knowledge E

© Carlos Romeiro and Pedro Araújo. This article is distributed under the terms of the [Creative Commons Attribution License](#), which permits unrestricted use and redistribution provided that the original author and source are credited.

Selection and Peer-review under the responsibility of the ICEUBI2019 Conference Committee.

1. Introduction

The age pyramid has been shifting in both western and eastern civilization, due to the decreased birthrate and higher life expectancy [1–4]. Through a sample collected from 8 countries between 2013 and 2018 the tendency is visible (please see Table 1).

The growing number of older people poses new challenges and opportunities in several sectors. Specifically in the health sector, where the resource shortage is a well-known limitation that already compromises the efficiency and availability of core services for the people well-being. As a response in the past few years there has

OPEN ACCESS

TABLE 1: Population evolution.

Country	Over 65 years old						Below 14 years old					
	2013	2014	2015	2016	2017	2018	2013	2014	2015	2016	2017	2018
Australia	13.45	13.71	14.02	14.35	14.68	14.98	18.88	18.83	18.84	18.90	19.01	19.14
Brazil	6.73	6.95	7.18	7.42	7.68	7.96	23.43	22.96	22.51	22.14	21.75	21.36
Canada	14.19	14.50	14.86	15.27	15.71	16.15	16.14	16.04	15.98	15.97	16.03	16.10
China	8.4	8.592	8.791	9.02	9.309	9.676	17.66	17.68	17.69	17.70	17.68	17.62
Portugal	18.69	19.06	19.46	19.88	20.31	20.74	14.44	14.26	14.08	13.86	13.63	13.40
Russia	13.09	13.12	13.17	13.23	13.33	13.49	15.94	16.42	16.83	17.29	17.61	17.82
United Kingdom	16.60	16.86	17.18	17.53	17.86	18.12	17.54	17.54	17.58	17.62	17.71	17.83
United States	12.97	13.24	13.56	13.90	14.27	14.64	19.23	19.04	18.89	18.72	18.62	18.56

been put an effort by both scientific and industrial community in the development of an Internet Communication Technology based solution; which could improve the end-user quality of life, assure the autonomy of users with special needs, reduce the costs related with medical assistance typically imposed by users from this population segment and address the healthcare services related needs – the AAL (Ambient Assisted Living) ecosystems [5].

Despite its development growth there are multiple challenges, which currently compromise their wide spread adoption by the main stakeholders. According to their nature they can be segmented into two domains: technical domain, related with the system's bottlenecks on a scientific standpoint; and end-user domain, related with the user's role within the system and his/her perception of the main barriers which compromise the acceptance/validation process. The technical related challenges identified were the following [5]–[11]:

- Security and usability – The design of medical devices used in an unsupervised context should follow a user-centric approach, since their target audience are the patients and medical professionals that use them for anomalous events monitoring in a daily basis;
- Autonomy and robustness – The devices are going to be used by a group of users with limited experience in terms of technology. Therefore factors, such as the device's autonomy, charging times and overall maintenance should be taken into account during the implementation phase;
- Culture – The AAL paradigm is perceived differently depending on the culture. For example in Japan robots are perceived as a viable solution to be integrated within these ecosystems, as opposed to Europe and United States of America, where

people are not willing to leave a sensible matter, such as health rehabilitation, to the control of an artificial entity [5]. Technophobia is a barrier to deal with, in order to adapt the products created to the user specific needs;

- Integration – System's implementation should assure a non-intrusive and seamless integration within the users' environment, through the discrete positioning of sensors and actuators to be used;
- Computer Human Interaction – The patient's need to interact with the system and the limitations of typical interfaces, such as the mouse or the keyboard, implies the development of direct and intuitive approaches, such as voice and gesture interaction;
- Data management – The volume and type of information collected by AAL ecosystems have increased substantially in terms complexity and mutability. Therefore the precision and accuracy of techniques and technologies used to collect, store, distribute, manage and analyze the sampled information (Big Data) should be maximized; and the data mining algorithms used to identify artifacts within big volumes of information should be optimized [12], [13].

In terms of end-user domain the challenges are the following:

- Privacy, control and intrusion level – Elderly users concern themselves with the misuse of the information collected by the ecosystem, and remain reluctant in relation to the system's inherent monitoring capabilities, due to its similarity to a vigilance process [14], [15];
- Perceived utility – According to the literature the lack of perception of the ecosystem usefulness compromises their acceptance. This perception is influenced by the user's health status, activity level and social influence. Note that the social factor, according to a study performed by the authors Golam Sorwar et al. [16], plays a major role. Additionally the dispositional resistance to change typically related with users from an advanced age also impacts negatively the system's overall experience and acceptance;
- Usability – The time required for the system to adapt to the user's needs and the learning curve are concerning factors. In the study undertaken by the authors Christina Jaschinski et al. it is noticeable the user's concern over the system's interface complexity and the level of intervention required, in order to assure the system expected behavior [17];
- Lack of human interaction – The effort performed in order to automate the use of the AAL ecosystems discards the human need to interact with other leading in

the long run to the patient's isolation. There is a consensus within the scientific community that technology should not be a replacement for human assistance or human interaction, therefore the inclusion of such automatism should take into account the typology of the task at end [17], [18];

- Stigmatization and pride – In the studies performed by Christina Jaschinski et al. [17] and Lars Tore Vassli et al. [18] the test subjects manifested against the use of technology, since it denoted them as frail or in need of assistance. Pride and embarrassment play a major role in what concerns the use the depicted ecosystems;
- Fear and low technological self-efficacy – Elderly people develop phobias driven by cognitive difficulties, lack of familiarity or low level of comfort with its use [17], [18];
- Reliability and trust – This is a sensible subject which concerns elderly people and even leads them to question if their well-being and security is not compromised by the use of such systems and technologies [18]. Technical anomalies, such as energy shortages and the occurrence of false positives are two of the most mentioned events in what system reliability is concerned. In the study from Christina Jaschinski et al. a set of tests to multiple monitoring systems revealed a significant number of false positive alarms triggered. However the way they were perceived depends from user to user, a portion considered that an inconvenience, while others saw as an indication of the system's correct behavior [17];
- Financial costs – Inadequacy of the practice prices considering the end-user financial capabilities [17], [18];
- Health concerns – Manifested concern in terms of the excessive electromagnetic exposure and its repercussion to the user health in the long run [17], [18].

Despite the number of challenges to tackle there has been a close collaboration between the main stakeholders, in order to address them accordingly. Specifically in what concerns the system's usability multiple studies have been performed to identify the key factors, which compromise it, and propose approaches/models which could aid in its analysis in multiple contexts [19]–[24]. However usability still remains an open issue in AAL ecosystems. As a result in this article the thematic will be explored thoroughly, in order to optimize the process used to maximize it through a practical use-case that enables the applicability of the heuristic principles depicted in the literature; and to identify which parameters could be used to evaluate properly each principle

in an methodic approach to minimize the process's subjectivity and improve its overall accuracy. To achieve this purpose it is required to understand what consists usability.

2. Usability

Usability is a product/service multidimensional property, which according to the ISO 9241-11, reflects the scope in which the end-user use it, in order to accomplish the purpose established in an effective, efficient and satisfactory way [25], [26]. Due to its scope and relation with the end-user, typically the term is mixed with other product/service property, user experience, whose analysis is related with factors from a personal, behavioral, social or environmental nature [27]–[29]. Despite both properties playing an important role in the development cycle, their analysis focus over different characteristics. Usability relates with the difficulty in which the user accomplishes his/her aim during the interaction process, while user experience focused over how the interaction process is perceived by the user [29].

In order to optimize usability it is required to identify guidelines/best practices to be adopted during the interfaces' design and development phase; methodologies used to verify and identify usability bottlenecks; and evaluation scales used to quantify the severity level of the flaws detected.

2.1. Best design practices

In a study performed by John D. Gould and Clayton Lewis, it was concluded that until the article's date the software development process lacked the definition of the design guidelines. As a result three usability principles were defined: user-centered development cycle, execution of empirical measurements and of an iterative design [30], [31]. Despite the meaningful effort in the definition of design best practices they were strongly criticized [32], [33]. In 2008 during a revision undertaken by the author Gilbert Cockton [34] it was concluded that despite their validity they have limited applicability in a real environment, which compromised their adoption and acceptance.

As consequence in 1990 the authors Jakob Nielsen and Rolf Molich [35] proposed a set of heuristic principles revised in 1994, which would become the pillars of the heuristic evaluation process in interface's usability [36], [37]. Principles such as (1) visibility of system status; (2) match between system and the real world; (3) user control and freedom; (4) consistency and standards; (5) error prevention; (6) recognition rather than recall; (7) flexibility and efficiency of use; (8) aesthetic and minimalist design; (9) help

users recognize, diagnose, and recover from errors and (10) help and documentation. In 1998 Ben Shneiderman proposed a set of eight design principles: (1) strive for consistency, (2) enable frequent users to use shortcuts, (3) offer informative feedback, (4) design dialog to yield closure, (5) offer simple error handling, (6) permit easy reversal of actions, (7) support internal locus of control and (8) reduce short-term memory load [38], [39].

2.2. Methodologies

The usability analysis imposes the implementation of interfaces, which take into account three phases of the development cycle: design, prototype and validation; and the adoption of user-centered methodologies, which assure the implementation of the technical and functional requirements in a real environment [28]. The usability evaluation methods cover all the development phases and are divided into three typologies: inspection, inquiries and test-based.

The inspection-based methods are an analytic methodology which imposes field related specialists, in order to perform an evaluation of the interaction between the user and the system. Within it are included techniques such as [27], [28], [40]:

- Heuristic evaluation – Evaluates the interface in terms of usability, efficiency and efficacy in an holistic manner;
- Feature inspection – Enumerates the features used to perform typical tasks in the interface; verifies the sequence of time consuming and critical steps not tested typically by the user, and the steps that require a certain degree of knowledge and experience in the domain;
- Consistency inspection – Implies the use of designers external to the project, to evaluate the interface in terms of consistency with the reference design [41], [42];
- Standards inspection – Implies the use of specialists in the field, in order to assure the interface compliance with industrial standards. Its applicability depends on the existence of well-defined standards that could be used by the evaluator [43].
- Formal usability inspection – Implies the use of a team of stakeholders and specialist in the area and assigns to each of them a system specific feature to be evaluated [44];
- Cognitive walkthrough – Focuses over the identification of user's interactions, objectives and design limitations which compromise the execution actions within the interface [45]–[49];

- Pluralistic walkthrough – Combines efforts from users, developers, designers and usability specialists, with the role of session moderators, to identify usability bottlenecks. The approach provides information related with the interface in a similar fashion to the test methodology approach and maximizes the accuracy of the bottleneck identification procedure [50], [51].

The **enquiries-based** methods are an empirical methodology which requires the execution of questionnaires developed and applied to the specified product/service's scope. Despite the subjectivity level of the information collected, it is undeniable their relevance for the extrapolation of the user real needs and identification of usability bottlenecks. Additionally the speed in which they can be executed and the low implementation cost make them a typical candidate for usability evaluation [28].

The **test-based** methods are an empirical methodology that imposes the evaluator to observe the users during the execution of the tasks within the interface in controlled environment, to collect data and extrapolate empirical evidence which allow him/her to optimize the usability of the interaction mechanisms. The techniques adopted to collect the information include execution of questionnaires from a wide range of complexity levels [40], [52].

3. Use Case

The purpose of the article is to perform a usability analysis of a typical AAL ecosystem through the use of a heuristic methodology. To optimize the applicability of the best design practices the process included all the principles depicted in the previous chapter, in order to identify similar principles across the multiple sets defined, propose a new set that takes into account the missing elements of each group and present an approach which can minimize the broad description that typically is related with the depicted principles and minimize both subjectivity within their interpretation and the gap between theoretical and practical application.

3.1. Ecosystem implementation

The analysis of the evaluation process requires the creation of an interface, which could present all the functionalities found in an AAL ecosystem, in order to have an environment as close as possible of traditional implementations. As consequence it was required to perform a feature analysis of the AAL ecosystems depicted in the

literature (1) and available for commercial use (2). Hence a total of fourteen solutions were analyzed, from which eight are presented in Table 2.

TABLE 2: Interface's features in AAL ecosystems.

#	Type	Features
[53]	1	<ul style="list-style-type: none"> •Login into the platform; •Presentation of the values collected by the ecosystem's sensors in multiple forms, being the chart restricted to the web-based interface; •Presentation of the manufacturer contact page restricted to the web interface; •Generation of air quality related notifications restricted to the web interface.
[54]	1	<ul style="list-style-type: none"> •Presentation of the values collected by the multiple sensors; •Generation of air quality related notifications.
[55]	1	<ul style="list-style-type: none"> •Login into the platform; •Presentation of the values collected by the multiple sensors; •Presentation of the patient profile (hospital platform only); •Presentation of the anomalies found within the user's datasets, whose visibility is restricted to the hospital institution platform; •Generation of notifications to inform the stakeholders of the registered anomalies.
[56]	1	<ul style="list-style-type: none"> •Monitoring of the blood's glucose level; •Patient's medication management; •Generation and share of reports with the patient's doctor; •Presentation of the values collected by the ecosystem's sensors in multiple forms in chart format; •Provision of a typical disease's frequently asked questions.
[57]	2	<ul style="list-style-type: none"> •Presentation of the measurements' history; •Recording of user's measurements; •Presentation of the data collected from the Kardia's device.
[58]	2	<ul style="list-style-type: none"> •Recording the blood's glucose levels, medication and meals taken; •Presentation of the changes in the blood sugar and carb intake.
[59]	2	<ul style="list-style-type: none"> •Presentation of the patient's location and the device's battery status; •Generation of anomalous event's notifications.

From the analysis undertaken a total of six main features were identified as the common ground among the solutions depicted. Note that each feature is given in a broad and generic description, in order to focus the core functionality depicted.

The core functionalities identified allowed to clarify what the interface had to include, in order to be an accurate representation to typical commercial and academic AAL ecosystem. As a result four screens were defined for the interface:

- Login screen - Provides the user crucial session mechanisms, such as account creation, account authentication and password recover;
- Timeline screen -Displayed after the user's authentication, which aims to provide the required mechanisms to check the user's measurement history in a timeline. It is composed by one section, general overview, in which the timeline and the respective components that allow the user to manage its inner navigation are presented.

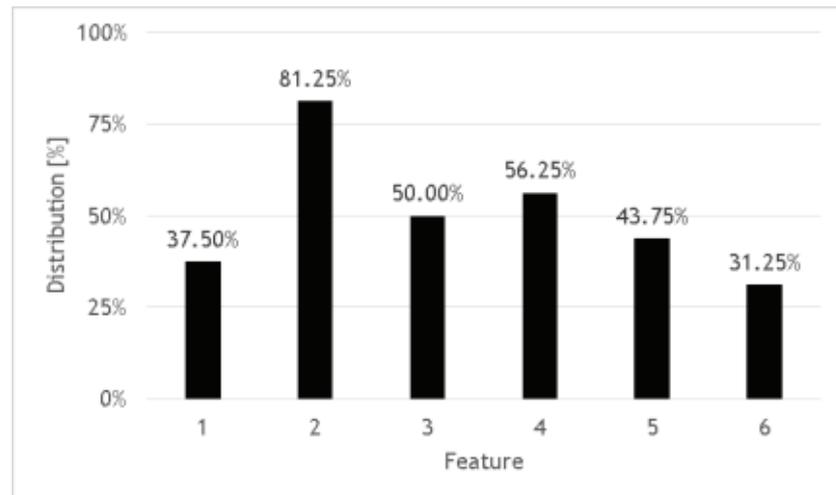


Figure 1: Feature distribution in a sample space of 16 solutions.

Legend: 1 - Login and logout; 2 - Display data collected from multiple sensors; 3 - Display a historic of the data collected; 4 - Record measurements; 5 - Generate user's notifications; 6 - Generate user's data reports.

- Sensors screen - Provides access to the sensors' management functionalities and allows to check their general information (name, state, type, actions among others). All the information is displayed in table format. Each table's row possesses an action's column where the management functionalities are accessible, such as the sensor's edition, removal, details visualization and help functionalities. The actions provided allow the user to navigate to two sections: details visualization, section in which the measurements collected from the respective sensor are displayed in table or chart format; details edition, section in which the user edits sensor's identification data, performs measurements and troubleshoots issues that occurred during the sensors operation with the ecosystem;
- Settings screen - Provides the platform main configuration mechanisms. Each mechanism was associated to distinct tabs: general tab, section in which the user is able to define certain platform look and feel properties (font type and size among others) for accessibility purposes; profile tab, section in which the user is able to edit the profile that was defined during the account creation process. In addition to the edition of the fields stated during the account creation process the user is able to define its profile picture; equipment tab, section in which the user is able to check in table format the multiple gateways used by the ecosystem, and the respective sensors connected to them; notifications tab, section in which the user is able to check in table format a summary of the triggered notifications per sensor; and data management tab, section created to provide the user an effective control over all the sensor's information collected by the ecosystem.

By taking into account the core functionalities which should be included in the interface, in order to replicate all the expected conditions found in a real environment the last choice resides in the selection of the interface type to be used. Since the target audience is the elderly it was opted to provide an interface presented and displayed in a common equipment, the home computer. Therefore it was opted to implement a web-based interface.

4. Heuristic Parameter Definition

The heuristic evaluation took into account Jakob and Schneiderman's usability principles to identify similarities and differences between them. Despite each principle's description aiming to aid in its quantification, the broad and generic sense in which they are provided can compromise the objectivity of the evaluation process and lead to multiple interpretations. Hence compromising the perception of how and what should be evaluated in each principle. In a standardization effort to improve the process's objectivity, accuracy and uniformity a set of parameters based on the principle core description were defined. According to the principle's scope two analysis typologies were applied:

- Component oriented (CO) – Focused over the compliance of the interface's components with the parameters defined. Its applicability implies the identification for each interface's screen of all the components in terms of type (active or passive), family (button, checkbox, input tag among others) and name;
- Action oriented (AO) – Focused over the actions which can be performed within the interface. Within this scope are included navigation and execution actions;
- Section oriented (SO) – Focused over the interface sections.

Note that the remaining principles were not described. The main reason being their conceptual similarity to principles, whose evaluation process had already been described. Principles such as "Strive for consistency", "Seek universal usability", "Prevent errors", "Permit easy reversal of actions" and "Reduce short-term memory load" share the same evaluation process described for their counterparts in Jakob Nielsen and Rolf Molich set respectively ("Consistency and standards", "Flexibility and efficiency of use", "Error prevention", "User control and freedom" and "Recognition rather than recall").

TABLE 3: Jakob Nielsen and Rolf Molich heuristic principles evaluation parameters [60].

Principle	Type	Parameters
1	CO	•Provisioning of feedback for each component's state (pressed, hover, dragged, enabled/disabled, on/off and error).
1	AO	•Provisioning of a progress bar indicator and of a closure dialog when applicable.
2	CO	•Provisioning of an icon within the component, which performs a match of the component purpose with a real world visual representation (for example the use of floppy disk to link the button to a save operation); •Lack of system terminology within component's text, hints or tips.
3	AO	•Reversibility of the action performed.
4	CO	•Assuring the compliance of the component structure and look and feel properties with preset values. This implies the definition of attributes - border radius, border width, border color, color, text style, sentence structure, icon existence and background color – whose values will be compared with the real implementation and allow to quantify the compliance level.
5	CO	•Restricting the user's input; •Provisioning of default parameters; •Disabling a control when the data required is missing; •Presenting a warning message reporting the user any unconformities within the input provided before the action is effectively performed.
6	CO	•Existence of a hint that clarifies the data type required; •Existence of a tooltip with the description of the action to be performed; •Existence of a label that clarifies the purpose of the action behind the control displayed •Existence of an icon that aids the user identify the component purpose; •Component consistency. (aids the user to perceive the component's purpose through the recollection of the aesthetic).
7	CO	•Assure typical shortcuts allow the navigation through the multiple components of the interface; •Assure the enter key has a similar behavior to mouse or touchpad click in terms of task execution.
8	CO	•Lack of highlights, shadows, glossy effects and 3D effects; •Provisioning of a contrast compliant with the interface accessibility guidelines (for example WCAG 2 AA, WCAG 2 AA - 18pt, WCAG 2 AAA and WCAG 2 AAA - 18pt).
9	AO	•Provisioning of an error message without any technical terms; •Provisioning of a constructive advice to recover from the error; •Provisioning of the reason which lead to the error.
10	SO	•Provisioning of a menu option to access the documentation and to request help.

5. Results

The interface created was evaluated in terms of compliance with the parameters defined for the Jakob Nielsen and Rolf Molich heuristic principles and Shneiderman's golden rules. The information was compiled in a chart format (please see Figure 2 and Figure 3).

TABLE 4: Shneiderman's golden rules evaluation parameters.

Principle	Type	Parameters
3	AO	<ul style="list-style-type: none"> •Provisioning of a task's completion rate and a progress bar for time consuming operations; •Clear indication of the current section.
4	AO	<ul style="list-style-type: none"> •Provisioning of a closure dialog.
7	AO	<ul style="list-style-type: none"> •Provisioning of a confirmation dialog.

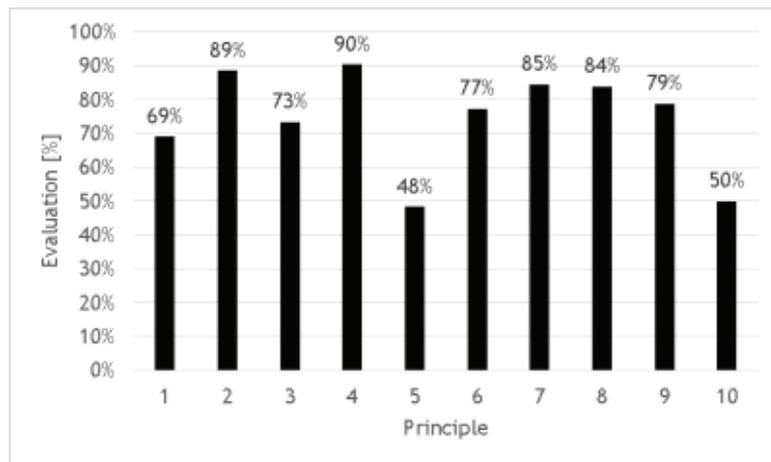


Figure 2: Evaluation score of each Jakob Nielsen's principle.

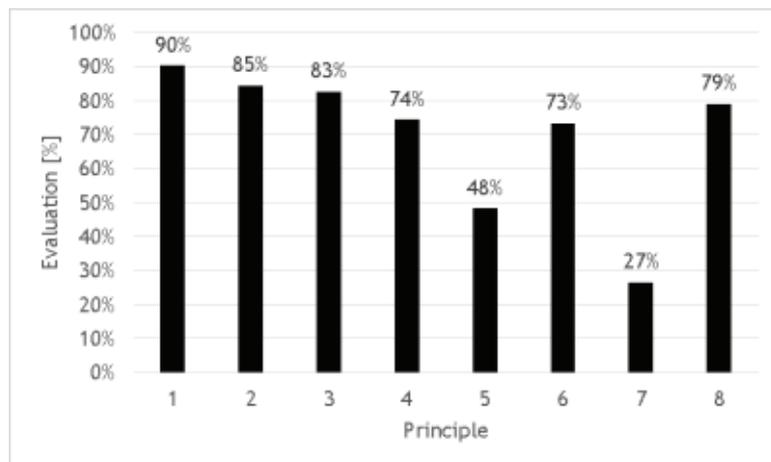


Figure 3: Evaluation score of each Shneiderman's rule.

In terms of the Jakob Nielsen and Rolf Molich principles the fifth (Error prevention) and the tenth (Help and documentation) are the ones with the lowest scores. Reason being that the inclusion of documentation within the interface was never considered during the interface implementation, and that the interface lacks the proper validation mechanisms to minimize the occurrence of errors created by the user input and the feedback capable of notifying the user an invalid input was introduced. For Shneiderman golden rules the

fifth (Prevent errors) and the seventh (Support internal locus of control) are the ones with the lowest scores. “Error prevention” was an already discussed topic by the previous principle set. In what concerns the “Support internal locus of control” principle, which relates to the need to maintain the user as an action initiator rather than a responder, the restricted use of confirmation dialogs to save operations within the interface lead to the depicted score.

6. Conclusion

The effort performed by the article allowed to stipulate a set of parameters to evaluate how the web interface was compliant with the principles defined. The parameters allowed to objectively analyze the heuristic principles provided, minimizing any subjectivity on the evaluator side. Despite the results giving an overall vision of the current interface bottlenecks, they do not assure the ecosystem’s interface usability. A second phase should be performed where the participation of the end-user is taken into account, in order to understand to what degree the quantification provided by the parameters stipulated match user real needs within the AAL ecosystem’s scope. Additionally it is intended to perform a similar analysis in terms of the remaining principle’s set, in order to identify, as it was performed in the use case, similarities and differences that can aid in the compilation of a set of principles that comply the best from each set with a clear specification of the standard parameters to be evaluated.

References

- [1] Eurostat, “Increase in the share of the population aged 65 years or over between 2008 and 2018,” 2019. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Population_structure_and_ageing. [Accessed: 13-Sep-2019].
- [2] United Nations, [World population prospects 2019]., no. 141. 2019.
- [3] Age UK, “Later life in the United Kingdom 2019,” no. May, 2019.
- [4] The World Bank, “Population ages 65 and above (% of total population),” 2017. [Online]. Available: <https://data.worldbank.org/indicator/SP.POP.65UP.TO.ZS>. [Accessed: 15-Sep- 2019].
- [5] K. Curran, Recent Advances in Ambient Intelligence and Context-Aware Computing, 1a Edição. IGI Global, 2014.
- [6] D. Z. A.V. Gundlapalli, M.-C. Jaulent, Ed., MEDINFO 2017: Precision Healthcare Through Informatics: Proceedings of the 16th World Congress on Medical and Health

- Informatics. 2018.
- [7] C. Van Den Broek, G., Cavallo, F., Wehrmann, AALIANCE Ambient Assisted Living Roadmap. IOS Press, 2010.
- [8] S. T. M. Peek, E. J. M. Wouters, J. van Hoof, K. G. Luijkx, H. R. Boeije, and H. J. M. Vrijhoef, "Factors influencing acceptance of technology for aging in place: A systematic review," *Int. J. Med. Inform.*, vol. 83, no. 4, pp. 235–248, 2014.
- [9] T. Greenhalgh, J. Wherton, P. Sugarhood, S. Hinder, R. Procter, and R. Stones, "What matters to older people with assisted living needs? A phenomenological analysis of the use and non-use of telehealth and telecare," *Soc. Sci. Med.*, vol. 93, pp. 86–94, 2013.
- [10] P. A. S. Duarte, F. M. Barreto, P. A. C. Aguiar, J. Boudy, R. M. C. Andrade, and W. Viana, "AAL Platforms challenges in IoT era: A tertiary study," 2018 13th Syst. Syst. Eng. Conf. SoSE 2018, pp. 106–113, 2018.
- [11] A. Mkpa, J. Chin, and A. Winckles, "Holistic Blockchain Approach to Foster Trust, Privacy and Security in IoT based Ambient Assisted Living Environment," no. January, 2019.
- [12] A. Ismail and A. Shehab, *Security in Smart Cities: Models, Applications, and Challenges*, no. November. Springer International Publishing, 2019.
- [13] V. Vimarlund and S. Wass, "Big data, smart homes and ambient assisted living.," *Yearb. Med. Inform.*, vol. 9, no. 1, pp. 143–9, 2014.
- [14] S. T. M. Peek et al., "Older Adults' Reasons for Using Technology while Aging in Place," *Gerontology*, vol. 62, no. 2, pp. 226–237, 2016.
- [15] J. L. Helbostad et al., "Mobile health applications to promote active and healthy ageing," *Sensors (Switzerland)*, vol. 17, no. 3, pp. 1–13, 2017.
- [16] R. Hoque and G. Sorwar, "Understanding factors influencing the adoption of mHealth by the elderly: An extension of the UTAUT model," *Int. J. Med. Inform.*, vol. 101, no. May 2018, pp. 75–84, 2017.
- [17] C. Jaschinski and S. Ben Allouch, "An Extended View on Benefits and Barriers of Ambient Assisted Living Solutions," ... *J. Adv. ...*, pp. 40–48, 2015.
- [18] L. T. Vassli and B. A. Farshchian, "Acceptance of Health-Related ICT among Elderly People Living in the Community: A Systematic Review of Qualitative Evidence," *Int. J. Hum. Comput. Interact.*, vol. 34, no. 2, pp. 99–116, 2018.
- [19] S. Macis et al., "Design and usability assessment of a multi-device SOA-based telecare framework for the elderly," *IEEE J. Biomed. Heal. Informatics*, vol. PP, no. c, pp. 1–1, 2019.

- [20] A. I. Martins and M. Cerqueira, "Ambient Assisted Living – A Multi-method Data Collection Approach to Evaluate the Usability of AAL Solutions," pp. 65–74, 2018.
- [21] J. D. Hallewell Haslwanter, K. Neureiter, and M. Garschall, "User-centered design in AAL: Usage, knowledge of and perceived suitability of methods," *Univers. Access Inf. Soc.*, vol. 0, no. 0, p. 0, 2018.
- [22] J. D. Hallewell Haslwanter, G. Fitzpatrick, and K. Miesenberger, "Key factors in the engineering process for systems for aging in place contributing to low usability and success," *J. Enabling Technol.*, vol. 12, no. 4, pp. 186–196, 2018.
- [23] T. Holthe, L. Halvorsrud, D. Karterud, K. A. Hoel, and A. Lund, "Usability and acceptability of technology for community-dwelling older adults with mild cognitive impairment and dementia: A systematic literature review," *Clin. Interv. Aging*, vol. 13, pp. 863–886, 2018.
- [24] A. Teixeira, A. Queirós, and N. P. Rocha, "Laboratório Vivo de Usabilidade," no. 1, 2013.
- [25] A. Application, "Mobile Application Usability Research Case Study of a Video Recording and Annotation Application," 2016.
- [26] ISO 9241-11, "Ergonomic requirements for office work with visual display terminals (VDTs) – Part 11: Guidance on usability," 1998. [Online]. Available: http://www.iso.org/iso/catalogue_detail.htm?csnumber=16883. [Accessed: 19-Apr- 2016].
- [27] S. Saeed, I. S. Bajwa, and Z. Mahmood, "Human factors in software development and design," *Hum. Factors Softw. Dev. Des.*, vol. i, pp. 1–354, 2015.
- [28] A. I. Martins, A. F. Rosa, A. Queirós, A. Silva, and N. P. Rocha, "European Portuguese Validation of the System Usability Scale (SUS)," *Procedia Comput. Sci.*, vol. 67, no. Dsai, pp. 293–300, 2015.
- [29] D. Quiñones, C. Rusu, and V. Rusu, "A methodology to develop usability/user experience heuristics," *Comput. Stand. Interfaces*, vol. 59, pp. 109–129, 2018.
- [30] I. Sciences, "Using tablet devices to control complex home appliances Aleksu Lintuvuori," Universidade de Tampere, 2015.
- [31] J. D. Gould and C. Lewis, "Designing for Usability: Key Principles and What Designers Think," *Commun. ACM*, vol. 28, no. 3, pp. 300–311, 1985.
- [32] L. A. Suchman, *Plans and Situated Actions: The Problem of Human-Machine Communication*. Cambridge: Cambridge University Press, 1987.
- [33] T. Winograd and F. Flores, *Understanding Computers and Cognition: A New Foundation for Design*, 61997o. Addison-Wesley Professional, 1986.

- [34] G. Cockton, "Revisiting usability's three key principles," in CHI EA '08 CHI '08 Extended Abstracts on Human Factors in Computing Systems, 2008, pp. 2473–2484.
- [35] R. Molich and J. Nielsen, "Communications of the ACM," 3, Nova Iorque, pp. 338–348, Mar-1990.
- [36] L. Salgado, C. Science, and P. Code, "Investigating performance characteristics of novice evaluators in heuristic usability evaluations," 2014.
- [37] A. P. G. D. Carrare, C. C. Hernandez, C. Kochi, I. F. Silveira, and C. A. Longui, "Usability Heuristics for Clinical Case-Based Learning Assessment Systems applied to Medical Education," 2015.
- [38] B. Shneiderman, "The Eight Golden Rules of Interface Design," 2010. [Online]. Available: <https://www.cs.umd.edu/users/ben/goldenrules.html>. [Accessed: 20-Sep-2019].
- [39] F. K. Mazumder and U. K. Das, "Usability Guidelines for usable user interface," Int. J. Res. Eng. Technol., vol. 3, no. 9, pp. 2319–2322, 2014.
- [40] A. I. Martins, A. Queirós, N. P. Rocha, and B. S. Santos, "Avaliação de usabilidade: Uma revisão sistemática da literatura," RISTI - Rev. Iber. Sist. e Tecnol. Inf., vol. 2013, no. 11, pp. 63–66, 2013.
- [41] J. Nielsen, "Summary of Usability Inspection Methods," 1995. [Online]. Available: <https://www.nngroup.com/articles/summary-of-usability-inspection-methods/>. [Accessed: 21-Sep-2019].
- [42] J. Nielsen, Coordinating User Interfaces for Consistency Interactive Technologies. 2014.
- [43] J. Hom, "Standards Inspections," 1995. [Online]. Available: <http://usability.jameshom.com/stdinsp.htm>. [Accessed: 21-Sep-2019].
- [44] Federal Aviation Administration, "Formal Usability Inspection." [Online]. Available: <http://www.hf.faa.gov/workbenchtools/default.aspx?rPage=Tooldetails&subCatId=13&toolID=78>. [Accessed: 02-May-2016].
- [45] C. Wharton, J. Rieman, C. Lewis, and P. Polson, "The cognitive walkthrough method: a practitioner's guide," in Usability inspection methods, Nova Iorque: ACM Digital Library, 1994, pp. 195–140.
- [46] P. G. Polson, C. Lewis, J. Rieman, and C. Wharton, "Cognitive walkthroughs: a method for theory-based evaluation of user interfaces," Int. J. Man. Mach. Stud., vol. 6, no. 5, pp. 741–773, 1992.
- [47] C. Lewis, P. G. Polson, C. Wharton, and J. Rieman, "Testing a walkthrough methodology for theory-based design of walk-up-and-use interfaces," in CHI '90

- Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1990, pp. 235–242.
- [48] L.-O. Bligård and O. Anna-Lisa, “Enhanced Cognitive Walkthrough: Development of the Cognitive Walkthrough Method to Better Predict, Identify, and Present Usability Problems,” *Adv. Human-Computer Interact.*, vol. 2013, p. 17, 2013.
- [49] M. S. A. R. R. K. V. A. Najmeh Ghasemifard, “A New View at Usability Test Methods of Interfaces for Human Computer Interaction,” *Glob. J. Comput. Sci. Technol.*, vol. 15, no. 1, 2015.
- [50] S. Riihiaho, *Experiences with usability testing: Effects of thinking aloud and moderator presence*. 2015.
- [51] W. Rödle et al., “User-Centered Development of an Online Platform for Drug Dosing Recommendations in Pediatrics,” pp. 570–579, 2019.
- [52] B. Martin, B. Hanington, and B. M. Hanington, *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions*. 2012.
- [53] G. Marques and R. Pitarma, “An indoor monitoring system for ambient assisted living based on internet of things architecture,” *Int. J. Environ. Res. Public Health*, vol. 13, no. 11, 2016.
- [54] G. Marques and R. Pitarma, “IAQ Evaluation Using an IoT CO₂ Monitoring System for Enhanced Living Environments,” *Adv. Inf. Syst. Technol.*, vol. 206, pp. 1169–1177, 2018.
- [55] M. Al-Khafajiy et al., “Multimedia Tools and Applications Remote health monitoring of elderly through wearable sensors,” 2019.
- [56] J. Pavlas, O. Krejcar, P. Maresova, and A. Selamat, “Prototypes of user interfaces for mobile applications for patients with diabetes,” *Computers*, vol. 8, no. 1, pp. 1–14, 2019.
- [57] AliveCor, “Kardia.” [Online]. Available: <https://www.alivecor.com/kardiamobile/>.
- [58] Azumio Inc., “Glucose Buddy Diabetes Tracker.” [Online]. Available: <https://apps.apple.com/app/id294754639>. [Accessed: 22-Sep-2019].
- [59] GreatCall, “GreatCall.” [Online]. Available: <https://www.greatcall.com/servicesapps/link>. [Accessed: 21-Sep-2019].
- [60] J. Nielsen, “10 Usability Heuristics for User Interface Design,” 1994. [Online]. Available: <https://www.nngroup.com/articles/ten-usability-heuristics/>. [Accessed: 20-Aug-2019].