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Set of Usability Heuristics for Quality Assessment of Mobile Applications on Smartphones

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ABSTRACT The innovations proposed by the cell phone market have grown steadily in recent years, along with the increasing complexity of the hardware, operating systems, and applications available in this market. These changes bring new challenges related to usability that need to be considered during the development process of these applications since the new forms of user-application interactions increasingly require adapting the behavior of smartphone users. In this situation, usability is an important issue that depends on factors such as the Users, their characteristics and abilities, the Task which the users intend to achieve and also the application usage Context. This work presents a systematic literature review with the objective of identifying the heuristics and usability metrics used in the literature and/or industry. Based on the review results, this work presents another contribution with a proposal of a set of usability heuristics focused in mobile applications on smartphones, considering the User, Task and Context as usability factors and Cognitive Load as an important attribute of usability. The components of this set are detailed in a model intended to be used in empirical validations allowing to dynamically incorporate improvements to the proposal.

INDEX TERMS Mobile applications, usability, usability heuristics, heuristic evaluation, cognitive load.

I. INTRODUCTION

The market for mobile devices has grown year after year, along with the evolution of these devices hardware capacities and the complexity of their operating systems and applications [1]. Another related change is the evolution from cell phones to smartphones, bringing ever new functions to the user, from the previously largely limited phone calls to the current much wider utilization, including listening music and other media, bank transfers, online purchases, among others [2]. This evolution brings new challenges that should be considered and studied for the development of a mobile application, including the key factor of software usability in this context [3].

Usability can be defined as "a broad concept that basically refers to how easy it is for users to learn a system, how efficient they can be once they have already learned it, and how enjoyable it is to use it" [4], i.e., usability is understood to be the ability to use a product with effectiveness, efficiency and satisfaction in a specific context of use [5].

Usability is a very important requirement of design, being of utmost importance to users in the decision to purchase a product, according to [11] which presents the "IS Success Model" showing, from the point of view of the product design, how a system is related to user satisfaction. This model allows to infer how the usability is a key factor to be considered in a product and/or software development process,

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so it is important to know how to apply it and to evaluate its results. The evaluation by means of usability heuristics allows the identification of usability problems and thus contributes to evaluating a software regarding its usability [11].

Usability heuristic evaluations describe design/usability principles that serve to evaluate a particular software. These evaluations are performed largely by usability experts or by ordinary users, although this latter group is less indicated [12], [13]. The evaluation of usability by means of heuristics has been widely studied and is one of the most used methods to evaluate the quality of a software, being considered in the literature as a traditional evaluation of software usability [14], [15].

The set of the ten heuristics proposed by Nielsen [16] is a classic in the literature and reveals principles for the construction of a software user interface that will probably show good usability. In the context of mobile applications, additionally to these factors pointed by Nielsen, new factors to be considered have arisen in relation to human-computer interaction and should be taken into account in the design and development of a software application that aims to have good usability. These factors bring as well a new set of usability heuristics which take into account such changes in evaluating the usability of mobile applications.

This work presents a systematic literature review (SLR) with the objective of identifying the usability heuristics for the mobile context proposed in the literature and also to identify the main metrics used in heuristic evaluations of a mobile application. Based on the SLR results, this work proposes a new set of usability heuristics specific to the context of applications for touch-screen smartphones. The proposed set takes into account the user, the context and the user performed tasks as usability factors [17]. Moreover, since Cognitive Load is considered as an important usability attribute [17], each proposed heuristic contains a detailed description to facilitate its understanding.

Differently from the approach of works that propose specific heuristics for a given context, such as Ajibola and Goosen [18] whose context is e-commerce, this work focuses on heuristics in the general context of mobile applications for touch-screen smartphones, according to the work developed by Salvucci [19], since more general heuristics for evaluating user interfaces generally become easier to understand and apply [20].

The general objective of this work is then to propose a set of usability heuristics focused on the context of mobile applications, detailing these heuristics and identifying the main metrics used during their evaluations. Therefore, the main contribution of this work is to propose a model that contains a set of specific usability heuristics for mobile applications, in the context of touch-screen smartphones, considering the user, the context and the tasks to be fulfilled in the application as usability factors and Cognitive Load as an important usability attribute.

This paper is organized as follows. Section II presents the theoretical basis necessary for the understanding of the other parts of this paper. Furthermore, this same section presents related works. Section III presents the performed systematic literature review and its results. Section IV presents the set of proposed heuristics to perform a heuristic evaluations of mobile applications. Section V presents the final considerations of this work, lessons learned and future work.

II. BACKGROUND

Mobile devices are electronic devices with some processing and storage capabilities and internet connection, whether intermittent or not, thus constituting a class of devices comprising smartphones, smartwatches, notebooks, GPS sensors, among others. Mobile devices are nowadays commonly used for communication and information treatment and three situations can influence their user interface design according to [21]: 1. When the devices are used by the user; 2. When devices are connected to the internet without the use of wireless cables; 3. When they support the addition of new applications and also an internet connection [22].

According to [23] there are other aspects that impact on the usability assessment of mobile devices, namely: 1. The generally reduced size while presenting a very large set of information; 2. The physical buttons that usually have more than one usage function; 3. The limited processing and memory resources.

The taxonomy presented by Schiefer and Decker [24] classifies mobile devices according to the following criteria: Size and weight, Input modes, Output modes, Performance, Type of use, Communication capacity, Type of operating system, and Expandability. This classification assumes that the device has a power source, a battery, and has the ability to communicate, both to receive and to send information (i.e., bidirectional communication). Touchscreen mobile devices are all those that have a touch screen, constituting a group which encompasses most types of mobile devices currently in use, such as smartphones and smartwatches, for example [24].

The term smartphone refers to a device that combines characteristics from Feature Phones (phones that have some more features than just those related to phone calls but with less features than a smartphone) and from Laptops, but generally containing a small screen and fewer features than a laptop computer. The main form of interaction with these devices is usually made by means of touch screens, mostly performed by a person's fingers or a special pen so that interaction events are recognized by these devices [22].

A. USABILITY

The International Organization for Standardization (ISO) together with the International Electrotechnical Commission (IEC) define usability in ISO/IEC 9241-11 [5] as: "the extent to which a product can be used by specific users to achieve goals (the accuracy and completeness with which users achieve the specified goals), efficiently (the resources expended in relation to the accuracy and completeness with which users reach goals), and with satisfaction (comfort and acceptability of use) in a specified context of use" [5], [25].

There are other standards that define what is important to be considered in terms of usability when the goal is software quality during the development process. The ISO/IEC 9126-1 standard [7] describes six categories of software quality factors that are relevant in the software development process, among which usability is basically defined as ease of use [7]. However, ISO/IEC 14598 [8] provides a framework for the use of the ISO/IEC 9126-1 model as a way to evaluate software products [8].

ISO/IEC 25000 [10] is a series of standards that came to replace and extend ISO/IEC 9126 [7] and ISO/IEC 14598 [8], with the main objective of organizing, improving and unifying concepts related to two major software development processes: specification of software quality requirements and software quality assessment, which are performed in conjunction with the software quality measurement process [10]. Usability is considered in every standard and is specifically mentioned also in DTR 25060, Common Industry Format (CIF) for Usability, and ISO 25062: 2006 [9], Common Industry Format (CIF) for usability testing reports [14].

Notwithstanding these official specifications, in the literature the term usability has several definitions. Shackel and Richardson [26] define usability as being the human functional capacity for a system to be used easily and efficiently by the specific user range, given specified training and user support, to meet the specified amount of resources within the specified number of scenarios.

Considered as pioneer researcher in the field, Nielsen proposed in his book Usability Engineering [27] that usability is composed of a set of paradigms, principles and attributes. In the quest to standardize concepts in this knowledge domain, Nielsen defined five attributes to characterize usability, i.e, attributes that impact on general usability and can be used to assist in the evaluation of a software application, comprising [14], [28]: **Efficiency; Learnability; Memorability; Satisfaction; Error**.

Usability Factors [29] are those that can affect the usability of a system, i.e., they can impact the overall design of the product and, in particular, can also affect user interactions with the application. According to Harisson *et al.* [17], there are three usability factors that must be considered:

1) **User**: The user is an important factor to be considered during the development process, as users have physical limitations and this fact can influence how a user uses a software application. Another important point is the user experience, whether or not the user is accustomed to using the application. A user that has enough experience with the application may want to use a more direct interface, even if it is a little less intuitive than that provided for novice users, for example, which will probably prefer a simpler and more intuitive interface.
2) **Task**: Task refers to the purpose that the user wants to achieve in using an application. An excess of functionalities can increase the application complexity, causing the overall application usability to be impaired, because it will be more difficult for the user to complete his goal.
3) **Use Context**: Context of use refers to the environment in which the user will use an application. It also refers to the user interaction with other people and also to other objects (such as an external device needed for the utilization of a mobile application). There are some utilization contexts that may influence the use of a mobile application, such as noted in the work of Bergman and Vainio [30], which shows an average decrease in walking speed when the user uses a mobile application while performing sports. Considering the impact that other tasks executed in parallel have in a mobile application usage, this is an important factor to be considered.

B. HEURISTIC EVALUATION

Heuristic evaluation is one of the most used usability evaluation methods [25]. This evaluation involves the participation of usability specialists, who analyze the interactive elements of a system, being guided by an established set of usability principles called heuristics [22]. Heuristics are written sentences regarding usability that represent principles or reflections that should be applied to an application interface by evaluators who have experience in the field of usability [31]. Heuristic evaluation can result in multiple enhancements to the mobile applications. An evaluation may show, for example, that mobile devices should incorporate a possibility to magnify text size, that the colors used should be neutral to improve contrast, and that the links should be more obvious and clearly labelled. Moreover, the consistency of navigation and icons placement should be improved [32].

This evaluation method proposes that each expert, who will perform the assessment, inspect the user interface to identify usability issues independently. If there are several evaluators, they should be organized so that each one evaluates independently of the others, and when everyone completes their evaluations, they can share their respective evaluations with the other evaluators. This restriction is necessary to ensure that the evaluations are independent and impartial from each other [22].

According to Nielsen [4], a number of 3 to 5 evaluators are generally required to carry out the heuristic evaluation, with a group of 3 users being considered the minimum necessary for evaluating more than 50% of problems in a user interface [33]. During the heuristic evaluation the evaluators conduct the product inspection several times, based on the interactive elements, and compare them with the heuristics that have been chosen for the case. For these reasons, heuristics should be selected to take into account the product context being evaluated, be it a physical product or a software, and its particularities.

C. USABILITY HEURISTICS

The widely known ten usability heuristics of Nielsen comprise [16]: 1. Visibility of system status;

2. Correspondence between the system and the real world; 3. User control and freedom; 4. Consistency and standards; 5. Prevention of errors; 6. Recognition and not remembering; 7. Flexibility and efficiency of use; 8. Aesthetic and minimalist design; 9. Clues to help users to recognize, diagnose, and recover errors; 10. Help and documentation.

Although these ten heuristics are the most used in the literature, in the related work of Dourado and Canedo [34] three additional usability heuristics are found from a systematic literature review to find heuristics of usability oriented to the mobile context. These heuristics aim to better align the set of heuristics to the context of mobile applications.

D. HEURISTIC EVALUATION FOR TOUCHSCREEN DEVICES

The heuristic evaluation may contain specific or general heuristics and the descriptions of both types should be easy to understand and apply. Very specific heuristics tend to become very difficult to apply in an evaluation, whereas more general heuristics, complemented by more specific heuristics, tend to work better most of the time because they do not require from the evaluator a very specific knowledge of a given context.

The heuristics proposed by Nielsen [16] are more general and not well suited for evaluating mobile applications such as those in touchscreen smartphones [22] since this evaluation requires more specific details.

Hence, to evaluate the usability of touchscreen devices, such as smartphones, it is important to consider some particular aspects of these devices that also influence their applications. According to Heo *et al.* [21], mobile devices are portable communication and information systems, and their interfaces are influenced by 3 important aspects: 1. Usually they are directly used by the user; 2. They are operated wirelessly; 3. They support new applications through an internet connection. According to Lee *et al.* [23], other aspects can be considered, including: 1. The devices have reduced screen size to display a large set of information; 2. Buttons usually have more than one feature; 3. The devices have limited processing capacity, battery and internal memory.

E. COGNITIVE LOAD

According to Feinberg and Murphy [35], the Cognitive Load concept can be defined as the necessary amount of ''mental energy'' for a person to process a given amount of information. As the amount of information increases, there is also an increase in the cognitive load in a person's mental resources. When the amount of information and instruction exceeds the capacity and limits of a person's mental resource, i.e., when the person can not absorb any more information given the large volume/amount of information given to that person, learning is inhibited [35].

Schildbach and Rukzio [36] present a paper comparing users of a mobile application to complete target selection tasks (when the user successfully selected a target, the visual and tactile feedback was provided) and also the task of reading, both with the user walking while performing such tasks. According to the results found by the authors, the users performance, when performing the proposed tasks, decreased and the cognitive load increased significantly. Furthermore, it was found that increasing the targets size on the device screen could cause an improvement in usability, while in the reading task, an increase in text size did not produce better usability results, since the need to scroll the text increased proportionately.

In the paper of Ahmad *et al.* [37] a set of usability heuristics for smartphones is proposed. In this work, Cognitive Load is defined as the amount of total effort in the operational memory, responsible for processing the information [38]. Thais paper states that the high Cognitive Load can lead the user to error [39] and low Cognitive Load can maximize user satisfaction and performance [40].

Harrison *et al.* [17] refer to Cognitive Load as the amount of cognitive processing a user needs to be able to use a software application. In traditional usability studies it is assumed, when the user, using a software application, performs only a single task, that the user can concentrate completely on that task because the user memory load is minimized. According to this same work, Cognitive Load is an important attribute which directly impacts and can be impacted by an application usability. For this reason, the present work proposes a model with a set of heuristics focused on three usability factors (user, context and task), as well as focusing on the Cognitive Load as an important usability attribute.

F. RELATED WORK

In the work of Miranda [41], a set of 16 heuristics focused on mobile devices is described. Furthermore, for the proposed set of heuristics, the work performs a heuristic evaluation in different mobile applications, given that they are characterized as being of different categories and containing different functionalities for proposal validation. The chosen mobile applications are: CNN, Amazon, TripAdvisor, Ebook Reader, Calendar, QR Code Scanner, Dropbox, Dictionary and Skype. These applications were tested on different mobile devices so that as many errors as possible were discovered. To cover more than one mobile platform, the study used the following devices: Smartphone Samsung Galaxy S4 running the Android system; iPad running the iOS system; HTC Titan running Windows Phone OS.

Miranda [41] concludes that with the popularization of mobile devices, such as smartphones, good usability in a mobile software application is a feature that distinguishes a successful software solution from others. Thus, the seek of excellence in an application usability should be a goal to consider during development. This cited work reinforces that heuristic evaluation is an adequate method to evaluate the usability of mobile applications, and that the set of proposed heuristics in the research can be improved so that more usability errors can be found through the heuristics evaluation method.

In the paper of Harrison *et al.* [17] a usability model called PACMAD (People at the Center of Mobile Application Development) is proposed which addresses the limitations

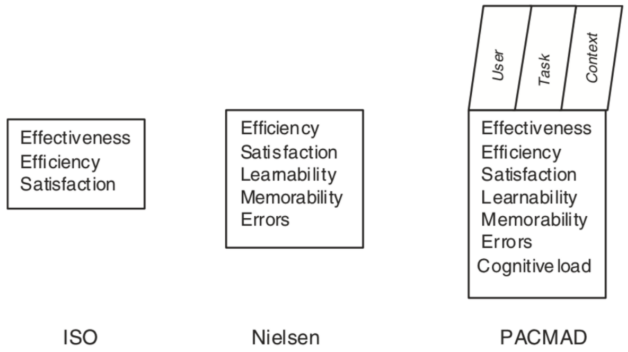

FIGURE 1. Comparison of usability models [17].

that the author believes to exist in other usability models when applied to mobile devices. Thus PACMAD brings important attributes of other usability models and is characterized as more comprehensive than these models.

Harrison *et al.* [17] compare their model with the usability models proposed by ISO 9241 [6] and Nielsen [4], resulting in data shown in Figure 1. The PACMAD model incorporates the attributes of the other two and adds Cognitive Load as a usability attribute for mobile applications. Furthermore, PACMAD proposes three usability factors, User, Task and Context, which the authors argue that are important when developing a mobile application, as it may impact the final interface of the system.

Gómez *et al.* [42] propose a list of focused heuristics for smartphones usability. This work first identifies the main limitations in the process of developing an interface for mobile devices, namely: limited input/output facilities, mobility and variable context, multi-device access types, limited processing and power capacity, and user adoption. Based on these studies, the work presents several general heuristics and sub-heuristics. Specifically, a set of 13 general usability heuristics is defined and for each one some specific heuristics for the context of mobile devices are proposed, while also emphasizing sub-heuristics focused on the general context of software applications, since the work argues that traditional sub-heuristics focused on computer applications do not fit the best detection of specific usability problems in the mobile context. The set of heuristics and sub-heuristics contribute to the avoidance of unidentified usability problems during application development, even with developers who are not specialized in performing a heuristic evaluation.

Ahmad *et al.* [37] propose a list of guidelines for heterogeneous cross-platform mobile applications. Usability guidelines can be classified into three distinct sets: platform-specific, gender-specific, and generic guidelines. The specific guidelines are for operating systems (for example, Android OS and iOS), being unique to each platform. Gender-specific guidelines are those that are unique to some application genre, such as health applications, games, and so on. Generic guidelines are those aimed at desktop applications, but by their generic nature, they can also be used for mobile applications.

TABLE 1. Research Questions (RQ) and Motivation for each RQ.

Research Question (RQ)	Motivation
RQ.1. What heuristics are used, in the context of mobile applications, to evaluate product quality?	Identify in the literature the heuristics used to evaluate the quality of mobile applications.
RQ.2. What are the usability heuristics used in the context of mobile applications that consider usability factors: user (its characteristics), task (user goal to be achieved in the application use), and context of use of the application?	Identify heuristics that focus on identifying how effective, efficient and satisfactory a mobile application is, having the user interaction with the system as the center of the evaluation.
RQ.3. What are the metrics used in a heuristic evaluation in the context of mobile applications?	Identify the metrics that are used for the heuristic evaluation.

The related works identified and reported in this paper present usability guidelines and heuristics for mobile applications, focusing on the user and the tasks that the user will perform when using a particular application. However, according to Harrison *et al.* [17], there are few usability works that consider context as a usability factor and the author argues that there may be a gap in the literature regarding this subject. Therefore, the present work seeks to propose a set of usability heuristics that consider the user, the task and the context as usability factors, thus contributing to minimize the mentioned gap on the subject in the literature.

III. SYSTEMATIC LITERATURE REVIEW

In this work the Systematic Literature Review (SLR) is used. The SLR is a framework that aims to provide a way to identify, analyze and interpret relevant research for a particular research question, area of knowledge or phenomenon of interest [43]. The studies that contribute to answer the research questions of a systematic review are called primary studies [43]. The SLR is performed in phase named Planning, Conduct and Publication of Results, as defined by Kitchenham [43]. Figure 2 presents these phases and the activities performed in each of the stages of SLR.

The StArt tool (State of the Art through Systematic Review) [45] was used to assist in the execution of the planning stages of this Systematic Literature Review. Furthermore, two complementary techniques were also used as described hereafter: Manual Search and Snowballing.

In order to guide the systematic literature review, the research questions and their motivations were defined, as described in Table 1, and were answered with the SLR.

The search strategy involved the use of Automatic Search, which consists of the search based on a search string in digital databases [46], followed by Manual Search, which searches for papers in Conference proceedings, Journals or specific Magazines [44]. Furthermore, Snowballing was applied [34]. The Automatic Search was performed in 5 databases, selected for having a considerable volume of papers published in periodicals and conferences of the knowledge area of usability, the focus of this SLR: ACM Digital Library; IEEEXplore; Science Direct; Scopus; Springer. The Manual Search was carried out by analyzing the titles and abstracts (if necessary)

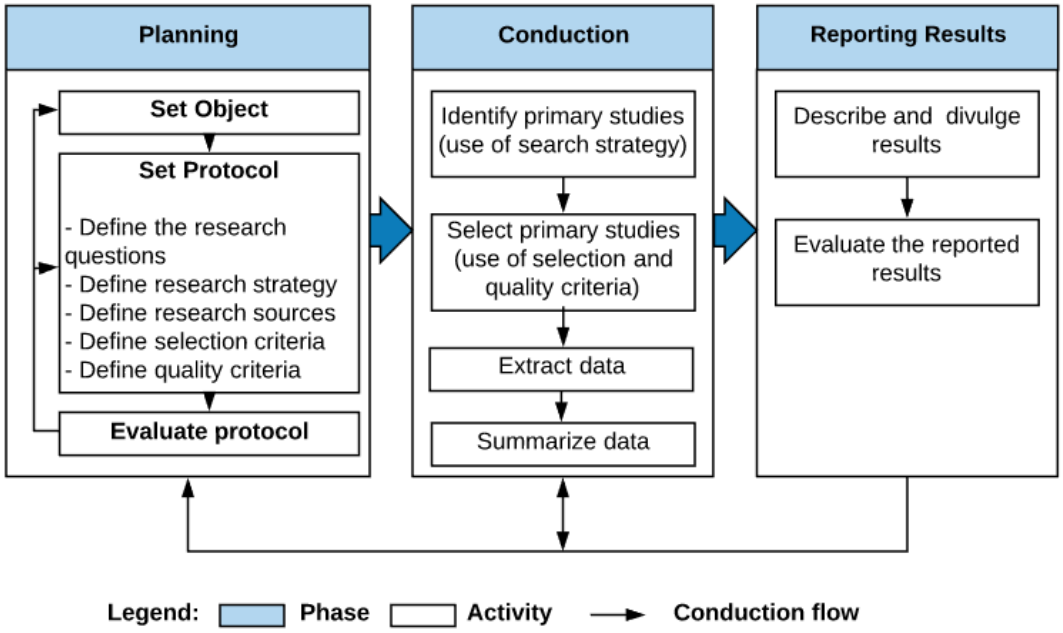

FIGURE 2. Phases and activities of the Systematic Literature Review [43], [44].

of studies published in Conferences Proceedings and Journals, dealing with Human-Computer Interaction. The studies considered potentially relevant were added to the set of selected papers.

The papers selected using the search string in the databases can represent results with some limitations, due either to the lack of keywords or synonyms in the String, or to the non-selection of a database that could return important works of the area in question. Even the way the String was defined can affect the results obtained in the SLR conduction [47]. To minimize the loss of important works, the present work decided to use Snowballing's set of instructions, as proposed by Wohlin and Prikladniki [47], which basically consists of reviewing the bibliographic references of the selected articles, with automatic and manual search, with the objective of selecting more works related to the research area.

The present work also defined selection criteria to include and exclude a primary study in our study object, according to the adopted research strategy. Thus, the inclusion and exclusion criteria were defined to select the most relevant papers in relation to the research questions to be answered. The inclusion criteria were defined to select papers that fit the needs of this research, which were:

1) Scientific papers which mention usability heuristics for mobile applications;
2) Papers which propose an approach, process or methodology to establish usability heuristics;
3) Research papers that propose a metric for evaluating usability heuristics for mobile applications;
4) Papers published between 2008 and 2018. However, classical sources with definitions (books with classical concepts or pioneering papers) were also considered.

Papers should be excluded using the following criteria: Research papers published as Short Papers.

A. SLR RESULTS

When applying the adopted automatic search strategy to the selected databases, from a total of 31 papers returned given the Search String, after reading the title, abstract and keywords, a number of 15 papers were selected and 16 excluded (Figure 3). Subsequently, the following steps of the adopted research protocol were carried out, resulting in the selection of 6 papers to answer the research questions and the exclusion of 9 papers. Thus, all steps of the adopted research protocol were performed and determined the complete reading of the 6 primary studies. Also fter the selection of the papers by the automatic search strategy, 1 paper was selected from the manual search and 1 through Snowballing, totaling **8 primary studies** for the extraction of data through the systematic review of literature (Figure 3).

The extraction of the information to compose the SLR result occurred through the complete reading of the 8 selected papers. From the complete reading of these primary studies it was possible to elaborate the answers to the research questions defined in this study.

1) RQ1 - WHICH HEURISTICS ARE USED IN THE CONTEXT OF MOBILE APPLICATIONS TO EVALUATE THE QUALITY OF THE PRODUCT?

The paper presented by Neto and Pimentel [48] (first line of Table 2), proposes a set of eleven usability heuristics focused specifically in the mobile context, presenting a comparison with the ten Nielsen's heuristics [16]. This comparison is a common procedure since Nielsen's work is a benchmark in

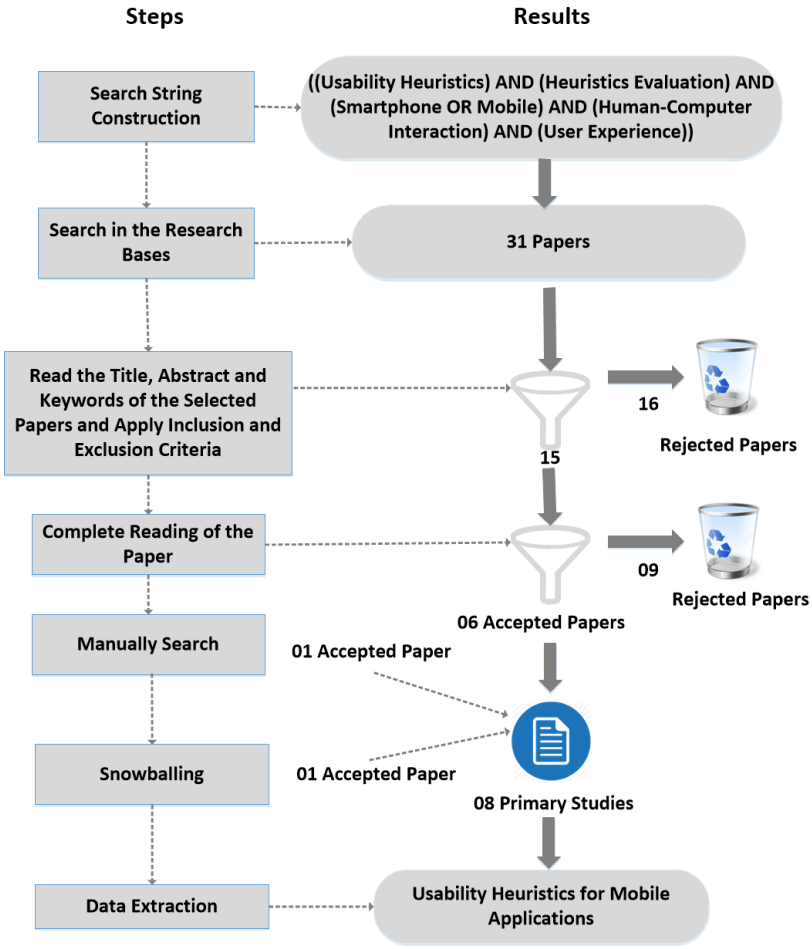

FIGURE 3. Result of the papers selection.

the area of usability in general. The objective of this paper is to compare the proposed heuristics with those of Nielsen in a practical study where the evaluators use the two models for future comparison of the final number of usability errors coming from both models. As a result, the model proposed by Neto and Pimentel [48] enabled the evaluators to find more interface usability errors than the Nielsen model [33].

Inostroza *et al.* [14] and [49] propose a set of twelve general heuristics for touchscreen-based devices (third line of Table 2). The set of proposed heuristics were refined from an evaluation with usability specialists divided into two groups. One group used the set of Nielsen's heuristics and the other group used the one proposed by the author in the evaluation of some applications. In the end it was concluded that the model proposed by Inostroza *et al.* [14], [49] captured more usability problems than the model proposed by Nielsen [33].

Humayoun *et al.* [50] propose a set of 15 heuristics focused on mobile applications that use multi-touch gestures (sixth line of Table 2). Based on the heuristic evaluation conducted by the authors, they concluded that through the proposed set of heuristics, the evaluators were able to find more usability problems than other heuristic proposals also focused on mobile applications, such as the paper of Joyce and Lilley [51], which also proposes a set of heuristics focused on the mobile context.

The work proposed by Billi *et al.* [52] presents a set of eight general usability heuristics focused on the mobile context (fifth line of Table 2). The author states that traditional heuristics, such as Nielsen's [16], do not deal with context switching and therefore new heuristics are required for better results in a heuristic evaluation for mobile applications.

There are some works that defend a set of heuristics for the mobile context that are more focused in some specific domain, according to the work presented by Ajibola and Goosen [53] (second line of Table 2). This paper presents a proposal of eleven heuristics, based on the heuristics of Nielsen [16], but focusing on the m-commerce context. The paper presents a revised proposal of heuristics as they have been re-evaluated with domain experts to improve and validate their proposal.

The work presented by Silva *et al.* [28] (fourth line of Table 2) propose a set of thirty-three usability heuristics (evolution of the work [54]) for the mobile context, focused on elderly users (senior citizens). The study presents the

heuristics grouped as follows: 1. **Perception**: these are heuristics related to the limitations of perception that the older user tends to suffer, such as: visual and auditory alterations; 2. **Cognition**: these are heuristics that refer to the cognitive changes that can occur with advancing age, such as the difficulty of maintaining attention or managing a large number of items in the working memory; 3. **Skill**: these are heuristics related to the difficulty in accomplishing tasks due to the limitations of the user's motor skills; 4. **Navigation**: these are heuristics directed to the understanding of the structure of the application and of how the user can use that application based on this structure; **Content**: these are heuristics related to the information and language used in the application; 6. **Visual Design**: these are heuristics that address design details, for example, formatting details and visual representations.

Table 2 and its continuation Table 3 present the usability heuristics that are used in the mobile context to evaluate product quality, according to the selected primary studies.

2) RQ2 - WHAT ARE THE USABILITY HEURISTICS USED, IN THE CONTEXT OF MOBILE APPLICATIONS, THAT CONSIDER USABILITY FACTORS: USER (ITS CHARACTERISTICS), TASK (USER GOAL TO BE ACHIEVED IN THE APPLICATION USE) AND APPLICATION USAGE CONTEXT?

In general, all the works that propose heuristics of usability seek to highlight the usability problems of a software application and, based on this, to determine if such application has good usability and is easy to use for users in general or for those with specific characteristics. Thus, there are papers that propose heuristics that evidence the usability factors proposed by Harrison *et al.* [17].

The first usability factor (user) is evidenced in all works that propose usability heuristics, since their purpose is to represent general principles of usability to be applied in a software interface, and based on that, the interface is expected to be easy and intuitive for the largest number of users with the most diverse characteristics. When the target audience of an application has more unique characteristics, such as some physical or mental limitation, the work is conducted with a focus on these more specific characteristics of the users. The paper presented by Silva *et al.* [28] (E5 from Table 2) suggests a set of focused heuristics for elderly users that usually have certain special characteristics that, according to the authors, may be psycho-social changes and functional disorders that affect vision, hearing, movement, cognition and their relationship to themselves and others around them. Thus, the heuristics that evidence the usability factor ''user'' in the authors' work (heuristics listed in the fourth line of Table 2) are: 1. Heuristics 2 and 3: Older users tend to be slower at performing tasks overall; 2. Heuristic 10: The characteristics of the target audience should be taken into account in the language used in the application; 3. Heuristics 13, 19, 20, 23, 24, 25, 26 and 27: Older users tend to have vision problems; 4. Heuristic 22: Older users tend to have hearing problems.

The second factor of usability (task) is evidenced in all works that propose a set of usability heuristics, since the main goal of the heuristics is to present general principles of usability, when applied in a particular software, if the final result is the best then the user is able to perform her/his tasks and achieve her/his goals in an easy and intuitive way when using software. This statement comes in line with the definition of usability given by Shackel and Richardson [26]. Thus, all the heuristics presented by Inostroza *et al.* [14], e.g., evidence the usability factor (task) proposed by Harrison [17], due to the fact that all heuristics are oriented towards maximizing the ease to achieve user goals in the most intuitive way possible.

The third factor of usability (context) is exactly the factor that Harrison [17] mentions as being a gap in the literature of works related to software usability. During the execution of this systematic literature review, no work was found containing context-oriented heuristics, reinforcing Harrison's assertion [17].

3) RQ3 - WHAT ARE THE METRICS USED IN A HEURISTIC EVALUATION IN THE CONTEXT OF MOBILE APPLICATIONS?

Gómez *et al.* [42] used a metric to prioritize the relevance of heuristic items to the specific interface being evaluated. Hence, the experts prioritized heuristics from 1 to 4 based on the application of evaluated software, being: 1 - for completed heuristic items, 2 - for those corresponding to usability gaps, 3 - for heuristic items that were not evaluated in the current phase of the software life cycle and 4 - for issues not applicable to the interface.

Inostroza *et al.* [49] conducted a study for the evaluation of their proposed heuristics, comparing them with the Nielsen heuristics [16], requiring two distinct groups of evaluators to evaluate a mobile application under egalitarian conditions. Inostroza *et al.* [49] used a metric that consisted in evaluating the severity of usability problems related to a given heuristic using a severity scale from 0 (low) to 4 (high).

Billi *et al.* [52] carried out a heuristic evaluation divided into three stages: pre-evaluation, individual evaluation and consolidation of individual findings. In the pre-evaluation phase the evaluators sign a consent form and a demographic questionnaire is given for the heuristic evaluation, as well as the instructions necessary for the evaluators to familiarize themselves with the set of mobile heuristics proposed by the author. In the individual evaluation phase, the evaluators sought to identify and prioritize usability problems based on the proposed heuristics. In the consolidation phase of the individual findings, the evaluators after completing the previous phase met to discuss the findings with the other evaluators. In the conducted heuristic evaluation, a metric proposed by Nielsen [27] was used to prioritize usability problems, which consists in evaluating the usability problem found for its severity on a scale of 0 to 4, being: 0 for no problems encountered, 1 for aesthetic problems found, 2 for minor usability problems found, 3 for found usability

TABLE 2. Identified heuristics for the mobile context in primary studies.

Primary Study(s)	Heuristics
[48]	(1)-Use of screen space; (2)-Consistency and standards; (3)-Visibility and easy access to all information; (4)-Adequacy of the component to its functionality; (5)-Adequacy of the message to the functionality and to the user; (6)-Error prevention and rapid recovery to the last stable state; (7)-Ease of input; (8)-Ease of access to all functionalities; (9)-Immediate and observable feedback; (10)-Help and documentation; (11)-Reduction of the userâĂŹs memory load.
[53]	(1)-Make the home page easy to glance over; (2)-Sense the usersâĂŹ fear of losing data; (3)-Include primary button under each product page; (4)-Be cautious with the inclusion of animated carousels; (5)-Be cautious of adding images or product information on different sub-pages; (6)-Be careful in the arrangement and design of account-selection options; (7)-Ensure that the auto-correction of the dictionary is disabled when weak; (8)-Ensure that fields are long enough to fully display common data (Add label on top of fields); (9)-Allow verification of inputted day and date; (10)-Ensure clear distinction of each hit area and list item; (11)-Ensure that usersâĂŹ privacy and security concerns are addressed.
[14], [49]	(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)-Minimize the user's memory load; (7)-Customization and shortcuts; (8)-Efficiency of use and performance; (9)-Aesthetic and minimalist design; (10)-Help users recognize, diagnose, and recover from errors; (11)-Help and documentation; (12)-Physical interaction and ergonomics.
[28]	**Cognition:** (1)-Focus on one task at a time instead of requiring the user to actively monitor two or more tasks, and clearly indicate the name and status of the task at all times; (2)-Avoid the use of interaction timeouts and provide ample time to read information; (3)-Avoid the use of animation and fast-moving objects; (4)-Leverage mental models familiar to older adults; (5)-Reduce the demand on working memory by supporting recognition rather than recall; (6)-Aim at creating an aesthetic user interface, by using pictures and/or graphics purposefully and adequately to minimize user interface clutter and avoid extraneous details. **Content:** (7)-Give specific and clear instructions and make help and documentation available. Remember that it is better to prevent than to recover from an error; (8)-Provide clear feedback and when presenting error messages make them simple and easy to follow; (9)-Make sure error messages are descriptive and use meaningful words and verbs when requiring an action; (10)-Write in a language that is simple, clear and adequate to the audience. **Dexterity:** (11)-Avoid pull down menus; (12)-Avoid the use of scrolling; (13)-Enlarge the size of user interface elements in general; targets should be at least 14mm square. **Navigation:** (14)-Keep the user interface navigation structure narrow, simple and straightforward; (15)-Use consistent and explicit step-by-step navigation. **Heuristic Description:** (16)-Make sure that the "Back" button behaves predictably; (17)-Support user control and freedom, allowing for alternative and flexible flows of interaction; (18)-Disable inactive user interface objects. **Perception:** (19)-Do not rely on color alone to convey information. Be aware of color blindness; (20)-Provide not only visual feedback, but also tactile and auditory; (21)-Make information accessible through different modalities; (22)-Use lower frequencies to convey auditory information such as confirmation tones and alerts; (23)-Do not use pure white or rapidly changing contrast backgrounds; (24)-Make it easy for people to change the text size directly from the screen.

TABLE 3. Identified heuristics for the mobile context in primary studies - continuation.

Primary Study(s)	Heuristics
	Visual Design: (25)-Use high-contrast color combinations of font and/or graphics and background to ensure readability and perceptibility; avoid using blue, green and yellow in close proximity; (26)-Use color conservatively, limiting the maximum number of colors in use to four; (27)-Make sure text uses types, styles and sizes appropriate to older adults, that is, for instance, but not exclusively: large-sized fonts, sans serif, non-condensed typefaces, non-italic, and left justified; (28)-Make links and buttons clearly visible and distinguishable from other user interface elements; (29)-Make information easy to read, skim (or) and scan; (30)-Group information visually (make good use of color, text, topics, etc.); (31)-Allow sufficient white space to ensure a balanced user interface design; (32)-Use user interface elements consistently and adhere to standards and conventions if these exist; (33)-Use simple and meaningful icons.
[52]	(1)-Visibility of system status and losability/findability of the mobile device; (2)-Match between the system and the real world; (3)-Consistency and mapping; (4)-Good ergonomics and minimalist design; (5)-Ease of input, screen readability and glanceability; (6)-Flexibility, efficiency of use, and personalization; (7)-Aesthetic privacy and social conventions; (8)-Realistic error management.
[50]	(1)-Visibility of system status; (2)-Matching between the system and the real world behavior; (3)-Navigation and user control; (4)-Consistency and standards; (5)-Realistic error management; (6)-Allow configuration options and shortcuts; (7)-Aesthetic and minimalist design; (8)-Help and documentation; (9)-Joy of use; (10)-Learnability; (11)-Cognitive workload; (12)-Fatigue; (13)-Recognition rather than recall; (14)-Do not lie to the user; (15)-Screen orientation.

problems that need to be fixed with a high priority and 4 for extremely urgent usability problems that must be repaired before the product is released to end users.

Humayoun et al. [50] conducted a heuristic evaluation with five expert evaluators in the field of computer science. The evaluation was conducted so that the evaluators were given a small training of 30 to 60 minutes to become familiar with the method. Thus, the evaluation scenarios were given to the evaluators and subsequently the actual heuristic evaluation was performed. The paper describes that the Likert scale metric was used [55] (Ajibola and Goosen [53] also use this the same metric) to classify the heuristics from 1 to 5 as to their usefulness during the evaluation, being: 1 - strongly disagree, 2 - disagree, 3 - neutral, 4 - agree and 5 - strongly agree.

4) DISCUSSION

The results obtained during the systematic literature review allowed the present work to identify some studies, such as the primary studies cited in the answer to the first question of research (RQ.1) of the SLR (Billi*et al.* [52], Inostroza *et al.* [14], Neto and Pimentel [48], Silva *et al.* [28], Inostroza *et al.* [49], Ajibola and Goosen [53] and Humayoun *et al.* [50]), which propose heuristics focused on the context of mobile applications, evidencing that there is little research related in the area and also that there is a gap, allowing space for new contributions.

The second question of the SLR in the present research showed that there are studies that consider the usability factors proposed by Harisson *et al.* [17], and the factors ''user'' and ''task'' were evidenced by the works referenced in this SLR. Being a heuristic a principle of usability that seeks to define standards to be followed by an application so that it can be used in an easy and intuitive way, hence the user can perform a specific amount of tasks in certain usage scenarios. Thus, this finding justifies that the present work considers the user and the task as usability factors. However, during the execution of the SLR, no work was found which presented usability heuristics related to the context as a usability factor, probably due to the complexity of evaluating with completeness the usability of an application, having the context as a variable to be considered.

The third question of research showed that the metrics used in a heuristic evaluation are relatively simple to represent, for instance, using the Likert [55] scale. Also, these metrics contribute to evaluate the severity of usability problems using heuristics and also to evaluate the heuristics regarding their usefulness to help the evaluator to find usability problems. Moreover, they allow the prioritization of heuristic items

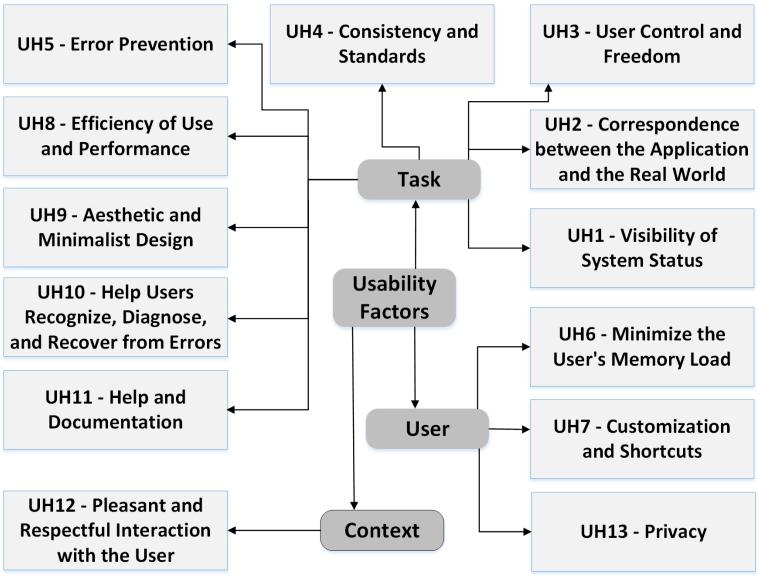

FIGURE 4. Disposition of usability factors in the proposed usability heuristics set.

based on their relevance for the specific interface to be evaluated.

IV. PROPOSED HEURISTICS SET FOR MOBILE APPLICATIONS

According to the results obtained with the conducted SLR, the present works proposes a set of heuristics for the evaluation of the usability of mobile applications. Figure 4 presents an overview of the proposed set. In this proposed set, each heuristic is structured with its respective ID; Name; Definition; Explanation; Primary Studies that justify its use; Benefits associated with the use of heuristics; and Problems associated with misinterpretation.

A. THE SET OF PROPOSED USABILITY HEURISTICS

1) UH1 - VISIBILITY OF SYSTEM STATUS

Definition: The application should keep the user informed about all processes and state changes within a reasonable period of time.

Explanation: By means of interaction with the application, the user must be able to perform different tasks. If user actions lead to a change of state of the application, the user must be informed in some way (for example: sounds, messages and/or animations on the screen). User actions such as gestures (touch screen and/or screen drag) should give feedback in a clear, concise and clear way.

Benefits: The user can have a better use experience when the application informs her/him about state changes, accurately and appropriately. Another benefit is related to the user's awareness when using the application, since her/him will know if there has been any significant change in the state of the application.

Problems: It is important to distinguish, when applying this heuristic, that the user may experience problems with the absence of feedback due to the lack of implementation of this functionality or application performance problems caused by a large number of concurrent processes and/or because of the low battery life, affecting application performance.

Studies that justify its use: Billi *et al.* [52], Inostroza *et al.* [14], Neto and Pimentel [48], Gómez *et al.* [42], Inostroza *et al.* [49] and Humayoun *et al.* [50].

2) UH2 - CORRESPONDENCE BETWEEN THE APPLICATION AND THE REAL WORLD

Definition: The application must speak the language of the users and not in technical terms of the system. The application must follow the conventions of the real world and display the information in a logical and natural order.

Explanation: Applications currently have multiple modes of interaction, where users can perform tasks in intuitive ways by mimicking real-world interaction rules. As an example, by scrolling down a long list, if the user ''slides'' with a certain speed, the list will continue to move, mimicking the effect of inertia. Another example is with respect to the multi-touch gesture in an application, when executing a gesture of sliding to the left the system must bring the next object of the right side, that is, showing the next image of the right side (as for example a carousel functionality). Each interaction is expected to show a response similar to that expected in the real world. In addition, the language (text or icons) must be related to the real world and recognizable concepts.

Benefits: By recognizing real-world concepts in the application, the user will have a smaller barrier to adapt to system usage and correctly interpret the information provided by the system as they will be presented in a logical and natural order.

Another benefit is the minimization of errors made by the user during the system usage, because the user will be more familiar with the application.

Problems: When applying this heuristic, it should not be confused with ''UH4 - Consistency and Standards''. If some parts of the system are in a different language, it is not a matter related to ''UH2 - Correspondence between the Application and the Real World'', but a matter of consistency.

Studies that justify its use: Billi *et al.* [52], Inostroza *et al.* [14], Gómez *et al.* [42], Inostroza *et al.* [49] and Humayoun *et al.* [50].

3) UH3 - USER CONTROL AND FREEDOM

Definition: The application should allow the user to undo and redo her/his actions for clear navigation and should provide the user with an option to exit undesirable system states.

Explanation: When the user makes a mistake by entering text, modifying configuration options or just reaching an unwanted state, the system must provide appropriate ''emergency exits''. These outputs should easily allow the user to move from an unwanted state to a desired one. Furthermore, the application should allow the user to undo and redo their actions in a simple and intuitive way, since users can often perform unwanted gestures on the touch screen of a smartphone (for example: touch, slide, etc.) which can take the application to another state.

Benefits: By having control over the system, the user has a greater sense of freedom, consequently a better user experience and a greater efficiency in the use of the application.

Problems: This heuristic should not be confused with the concept of flexibility and efficiency of use. Although some control effects are related to better efficiency (as pointed out in the Benefits above), they are dissimilar concepts. The heuristic ''UH3 - User Control and Freedom'' is intended to repair or fix errors, giving the user a chance to undo or redo her/his actions and have control over the features of the device.

Studies that justify its use: Inostroza *et al.* [14], Gómez et al [42], Silva *et al.* [28], Inostroza *et al.* [49] and Humayoun *et al.* [50].

4) UH4 - CONSISTENCY AND STANDARDS

Definition: The application must follow the established conventions, allowing the users to perform their tasks in familiar, standardized and consistent manner.

Explanation: Often, different parts of the application that are related and should be similar have different design or logic of use. In general, any concept presented in a way that contrasts with the conception of the concept by the user produces confusion to some degree. This confusion can lead to a decrease in use efficiency or a low satisfaction, among other side effects. A particular gesture of user interaction in the system interface should trigger the same behavior throughout the application. Also, it is better to avoid conflicts with the operations triggered by a gesture in the application and the operations related to the default gestures of the operating system. Given all these questions, it is expected that the system will follow standards and conventions for an intuitive and user-friendly interface.

Benefits: The application that follows conventions and standards causes new users to have a lower learning curve while using the system, which benefits from the experience gained from using other applications. Thus, errors made by the user in the interactions with the application will be minimized, as the user will be familiar with the system navigation.

Problems: When one speaks of consistency, one classic aspect is the consistency of the language. Sometimes there are words that do not have proper translation, especially when related to technology. These words can be difficult to translate or even lose meaning. So keeping some words in another language may not be a ''consistency'' problem, but keeping an integer paragraph is definitely one.

Studies that justify its use: Billi *et al.* [52], Inostroza *et al.* [14], Neto and Pimentel [48], Gómez *et al.* [42], Inostroza *et al.* [49] and Humayoun *et al.* [50].

5) UH5 - ERROR PREVENTION

Definition: Eliminate error prone conditions and give the user a confirmation option with additional information before committing to the action.

Explanation: The application should try to be explicit about each option and functionality available to the user. Considering a limited screen space, this can be a big challenge. Thus, the icons play a very important role, such as giving a return to the user when it interacts, and even if the visible part of the icon may be small, there must be some invisible destination extra space that, if a user reaches this space, the interaction will still occur. Unfortunately, sometimes a small image is not enough to describe in detail a function or something similar, and to fix this, the system must provide additional information on user demand. The information should be clearly displayed, trying to avoid long dialogue sequences. Furthermore, the user should be warned, especially when there are some actions that may have undesired effects on the user.

Benefits: By preventing the user from making mistakes, the user will spend less time trying to solve them, which can lead to greater efficiency.

Problems: This concept should not be confused with ''UH10 - Help Users Recognize, Diagnose, and Recover from Errors''. If the user can trigger an error, this is a prevention problem.

Studies that justify its use: Inostroza *et al.* [14], Neto and Pimentel [48], Gómez *et al.* [42] and Inostroza *et al.* [49].

6) UH6 - MINIMIZE THE USER'S MEMORY LOAD

Definition: The application should provide visible objects, actions, and options to prevent users from having to memorize information from one interface to another.

Explanation: Short-term human memory is limited, so the user should not be forced to remember information from one part of the system to another. Instructions on how to use the

system should be visible or easy to obtain. When using applications that run on mobile devices, users are often performing other tasks at the same time they are using the application, such as exercise monitoring applications that are used during physical activity, the interface must be adapted to the context of use so that the user's cognitive load is minimized.

Benefits: By reducing memory load, the user's mental capacity and effort is also reduced and the user can focus on performing a single task more efficiently.

Problems: For this specific heuristic, the evaluator may encounter some problems related to error prevention. The main point here is to note that this heuristic is strongly related to information overload. It is not about the availability of information, but about the amount of information that the user needs to memorize to use the system correctly and more efficiently, based on the context of use of the application.

Studies that justify its use: Inostroza *et al.* [14], Neto and Pimentel [48], Silva *et al.* [28] and Inostroza *et al.* [49].

7) UH7 - CUSTOMIZATION AND SHORTCUTS

Definition: The application should provide basic and advanced settings for setting and customizing shortcuts for frequent actions.

Explanation: Each user has her/his own needs and trying to satisfy them all with a standard menu or interface can be challenging. Thus, consider allowing users to create their own shortcuts and customizing most parts of the system can help. By means of advanced configuration options, savvy users can improve their usability and new users can have a deeper sense of ownership. It is important to look at the characteristics of the target audience of the application, because this mapping allows to implement more or less advanced customization options, for example.

Benefits: The user being able to customize some actions and/or features has a deep sense of ownership. The same is true by facilitating user access to features that are more used, and better tailoring the application to the user profile. Shortcuts contribute to achieving efficiently the goals and thus provide real benefits to the user, such as maximizing battery efficiency.

Problems: Clearly, there is a limit in terms of customization. Aesthetic modifications may be possible in most parts of the system, but some things are not achievable. Significant changes must be analyzed on a case-by-case basis as to their implementation validity, and it is necessary to consider the profile of the target public in the analysis.

Studies that justify its use: Inostroza *et al.* [14], Inostroza *et al.* [49], Ajibola and Goosen [53] and Humayoun *et al.* [50]

8) UH8 - EFFICIENCY OF USE AND PERFORMANCE

Definition: The device must be able to load and display information in a reasonable amount of time and minimize the steps required to perform a task (number of steps to be taken by the user to reach a goal). Animations and transitions should display smoothly.

Explanation: The combination of hardware features and software needs is not always the best. The basic application is expected to be compatible with the hardware, especially with processing capabilities, to avoid black screens and long waiting times. Furthermore, animations, effects, and transitions should be displayed seamlessly and without interruption. Another critical point is the length of the sequence of steps to perform a task. Complex, potentially dangerous or infrequent tasks may contain several steps to enhance security. Simple or frequent tasks should be short, that is, have few steps to complete.

Benefits: Lower response times and better performance, which leads to an efficient system.

Problems: Problems related to hardware performance should be separated from problems related to network performance. Even though these problems affect usability, they are not part of the scope of this research, considering that they are affected by several complex factors. In relation to the duration of a sequence of steps to perform a task, the limit between normal and excessive is a subjective matter. The evaluator should use his or her own criteria.

Studies that justify its use: Billi *et al.* [52], Neto and Pimentel [48], Gómez *et al.* [42] and Inostroza *et al.* [49].

9) UH9 - AESTHETIC AND MINIMALIST DESIGN

Definition: The application should avoid displaying unwanted information that overwhelms the screen.

Explanation: The application texts should not contain irrelevant or rarely needed information. Each extra unit of information in one interface competes with other relevant pieces of information that may be in the interface, causing extra information to decrease the visibility of relevant information in the application interface. Designers should be careful when displaying information across the screen. Additionally, overloaded interfaces can produce stress for the user and can also increase the consumption of application resources on a smartphone.

Benefits: If the application uses a minimalist design, the device uses less resources, which should lead to better performance, and also minimizes the amount of user visual information that can lead to less stress and exhaustion.

Problems: To distinguish between a minimalist design and an overloaded interface, it is necessary for the evaluator to define a subjective criterion at the time of evaluation. If the evaluator faces an overloaded interface, there is clearly a problem related to this heuristic.

Studies that justify its use: Billi *et al.* [52], Inostroza *et al.* [14], Gómez *et al.* [42], Inostroza *et al.* [49] and Ajibola and Goosen [53].

10) UH10 - HELP USERS RECOGNIZE, DIAGNOSE, AND RECOVER FROM ERRORS

Definition: The application should display error messages in a language familiar to the user, accurately indicating the problem and suggesting a constructive solution.

Explanation: When an error occurs, the user does not need technical details or cryptographic alert messages, but clear messages in a recognizable language with instructions on how to recover from the error. If possible, the application should constructively suggest a solution (which may also include tips, frequently asked questions, etc.). If there is no solution to the error, or if the error has an insignificant effect, the application should allow the user to handle the error normally.

Benefits: Being able to get help messages and instructions on how to recover from the error, the users are aided to reduce their frustration in dealing with the error.

Problems: The evaluator must distinguish between prevention and help to recover from the error. The main difference here is the timing. If the error has not yet happened, the case is about prevention, otherwise it could be a problem related to this heuristic.

Studies that justify its use: Billi *et al.* [52], Inostroza *et al.* [14], Gómez *et al.* [42], Inostroza *et al.* [49] and Humayoun *et al.* [50].

11) UH11 - HELP AND DOCUMENTATION

Definition: The application should provide easy-to-find documentation and help centering on the user's current task and indicating concrete steps to follow.

Explanation: The application must provide access to detailed information about the available features in a clear and simple way, from any part or state of the system where the user is located. It is recommended that this information be included in the application and easily accessible, or otherwise, that the documentation be available on a website. For very complex or somewhat difficult interactions for novice users to understand, such as multi-touch gestures on a touchscreen smartphone that can be difficult, in this case it is advisable to present tutorials, documentation and help for users to be elucidated about the correct form of execution of the gesture and so the user reaches its goal in the use of a certain functionality of the application.

Benefits: Through greater knowledge of the system, the user tends to make a smaller number of errors and to have a greater efficiency in the use of the application, as well as, she/he can gain a better knowledge of the system through a rich documentation and also can reduce the risk of making mistakes.

Problems: The main difficulty in applying this heuristic is how to differentiate it from error prevention. Even though documentation and help messages can prevent errors, this heuristic is very focused on instructions on how to use the system (such as user gesture interaction), additional options and configuration information, and so on.

Studies that justify its use: Billi *et al.* [52], Inostroza *et al.* [14], Gómez *et al.* [42], Inostroza *et al.* [49] and Humayoun *et al.* [50].

12) UH12 - PLEASANT AND RESPECTFUL INTERACTION WITH THE USER

Definition: The device should provide a nice interaction with the user so that the user does not feel uncomfortable while using the application.

Explanation: Mobile applications are designed to be used on portable devices (smartphones). From this point of view, ergonomics and comfort play a very important role in the interaction between the user and the application. Buttons should be placed in user-recognizable positions based on their experience with other similar applications. Furthermore, it is necessary to analyze the context of use in which the application will be inserted, such as a runner oriented application that will be used during sports practice, there must be a fully sloped interface for user comfort and ergonomics during the use of the application regarding the arrangement of the elements. The interface as a whole has to be focused on the characteristics of its target audience, and can include users with general characteristics and/or also the most specific ones, such as, for example, elderly users that tend to have certain special characteristics, such as: psycho-social and functional changes which affect vision, hearing, movement, cognition and their relation to themselves and others around them, such factors influence the way the elements are arranged at the interface.

Benefits: The application becomes more intuitive using layout elements in the interface that are familiar to the user, such as putting buttons in recognizable positions or when varying the orientation of the application between vertical and horizontal dispositions, the interface maintain the same layout of the elements on the screen. Adapting the entire application interface, taking into account the user's characteristics as well as the usage context, makes the end user more efficient in interactions with the application.

Problems: A possible problem in applying this heuristic may be the case of users with special needs/characteristics. In this case, the appraiser must use his or her own discretion. There are applications that may be uncomfortable for most users and this is a problem related to this heuristic. A very important aspect to consider is ''popularity'', that is, what best suits most users. However, each case should be analyzed separately and the evaluator should establish its criteria.

Studies that justify its use: Inostroza *et al.* [14], Gómez *et al.* [42] and Inostroza *et al.* [49].

13) UH13 - PRIVACY

Definition: The application must protect the user's sensitive data.

Explanation: The application should request the user's password for the modification of important data, as well as provide information about how the user's personal data is protected, as well as about copyright content.

Benefits: The users will get greater satisfaction and trust in the application knowing that their personal data is protected.

Problems: The purpose here is not just documentation or ways to inform the user of the protection methods used, but in fact to have features within the application that ensure the privacy of user data (such as differentiated data views for the user and her/his followers in a social networking application).

Studies that justify its use: Gómez *et al.* [42] and Ajibola and Goosen [53].

The proposed model presents general heuristics for the context of mobile applications. The context of use and the characteristics of the user are considered for conducting heuristic evaluations based on the proposed model. Thus, the proposed heuristics include requirements for evaluating applications to be used by people of different cultural and social situation, such as: children, adults, and the elderly. For instance, heuristic named ''UH13 - Privacy'' can be further detailed to include rules and metrics to evaluate application options designed to allow the user to hide/show data regarding gender, religion, age. Furthermore, the proposed heuristics are also appropriate to evaluate applications that are used by people with disabilities. For instance, heuristic named ''UH12 - Pleasant and Respectful Interaction with the User'' can be further detailed to include rules and metrics to evaluate sounds and automatically synthesized text readings used by an application to help people with vision disabilities. Thus, since usability is essential in regard of any cultural/social or physical aspect, the proposed model is designed to evolve integrating more detailed metrics and evaluation rules related to the chosen usability heuristics.

V. CONCLUSION

Usability is a key differentiation factor for smartphone products and mobile applications and is also a fundamental attribute for the quality of the product. Since it is a factor that facilitates the tasks for the user, usability can help in acquiring the loyalty of the user and his satisfaction in using a software application.

As the usability heuristics of Nielsen [16] were not developed to encompass mobile applications [48], this fact motivated the present work to answer the need to identify and propose a new set of heuristics that focus on applications in the mobile context, thus extending the previous related work of Dourado and Canedo [34].

Therefore, the present work proposes a set of usability heuristics that consider the user, the task performed by the user and the context as usability factors. The proposal considers the works identified through a systematic literature review carried out in this knowledge domain. Furthermore, this review allowed to clarify the research questions that were proposed, and based on the results encountered, to propose the set of heuristic of this paper.

Besides the interesting and discussed results of the performed systematic literature review, the main contribution of the present work is then a set of general heuristics for the context of mobile applications, highlighting usability factors proposed by Harrison *et al.* [17] and including Cognitive Load as an important attribute of usability. Also, the conduction of the systematic literature review identified the metrics that are used by researchers in evaluations of usability heuristics.

A possible future work consequent to the presented results consists in carrying out usability evaluations regarding applications developed with interfaces for people with and without disabilities. Since these applications can be evaluated in two different contexts regarding disabilities, the results can be compared to identify the need to include some specific usability heuristics in this context. This will allow to extend the proposed model in a systematic inclusive approach recognizing the diversity of cultural and social situations of mobile application users.

REFERENCES

[1] *The Evolution of Smartphone Markets: Where Growth is Going*. Accessed: Jun. 5, 2018. [Online]. Available: http://www.nasdaq.com/article/the-evolution-of-smartphone-markets-where-growth-is-going-cm619105

[2] H. Al-Nuiam and L. M. Al-Harigy, ''User interface context of use guidelines for mobile apps,'' *Int. J. Recent Trends Hum. Comput. Interact.*, vol. 6, pp. 65–80 Aug. 2015.

[3] A. de Lima Salgado and A. P. Freire, ''Heuristic evaluation of mobile usability: A mapping study,'' in *Proc. 16th Int. Conf. Hum.-Comput. Interact., Appl. Services (HCI)*, Jun. 2014, pp. 178–188. doi: 10.1007/978-3-319-07227-2_18.

[4] J. Nielsen, ''Usability inspection methods,'' in *Proc. Conf. Hum. Factors Comput. Syst. (CHI)*, Apr. 1994, pp. 413–414. doi: 10.1145/259963.260531.

[5] *Ergonomic Requirements for Office Work With Visual Display Terminals (VDTs)—Part 11: Guidance on Usability*, Standard ISO 9241-11:1998, Geneva, Switzerland, 1998. [Online]. Available: https://www.iso.org/standard/16883.html

[6] *Ergonomics Requirements for Office Work with Visual Display Terminals (VDTs)*, Standard ISO 9241:1997, Geneva, Switzerland, 1997. [Online]. Available: https://www.iso.org/standard/21922.html

[7] *Software Engineering—Product Quality*, Standard ISO/IEC 9126-1:2001, Geneva, Switzerland, 2001. [Online]. Available: https://www.iso.org/standard/22749.html

[8] *Information Technology–Software Product Evaluation–Part 1: General Overview*, Standard ISO/IEC 14598-1:1999, Geneva, Switzerland, 1999. [Online]. Available: https://www.iso.org/standard/24902.html

[9] *Systems and Software Engineering–Systems and Software Quality Requirements and Evaluation (SQuaRE)–Guide to SQuaRE*, Standard ISO/IEC 25000:2005, Geneva, Switzerland, 2005. [Online]. Available: https://www.iso.org/standard/64764.html

[10] *Software Engineering–Software Product Quality Requirements and Evaluation (SQuaRE)–Common Industry Format (CIF) for Usability Test Reports*, Standard ISO/IEC 25062:2006, Geneva, Switzerland, 2006. https://www.iso.org/standard/43046.html

[11] Z. Mack and S. Sharples, ''The importance of usability in product choice: A mobile phone case study,'' *Ergonomics*, vol. 52, no. 12, pp. 1514–1528, 2009. doi: 10.1080/00140130903197446.

[12] J. Nielsen and R. Molich, ''Heuristic evaluation of user interfaces,'' in *Proc. SIGCHI Conf. Hum. Factors Comput. Syst. (CHI)*, Seattle, WA, USA, Apr. 1990, pp. 249–256. doi: 10.1145/97243.97281.

[13] J. Nielsen, ''Guerrilla HCI: Using discount usability engineering to penetrate the intimidation barrier,'' in *Cost-Justifying Usability*. Orlando, FL, USA: Academic, 1994.

[14] R. Inostroza, C. Rusu, S. Roncagliolo, and V. Rusu, ''Usability heuristics for touchscreen-based mobile devices: Update,'' in *Proc. 1st Chilean Conf. Hum.-Comput. Interact. (ChileCHI)*, Temuco, Chile, Nov. 2013, pp. 24–29. doi: 10.1145/2535597.2535602.

[15] J. Kjeldskov and J. Stage, ''New techniques for usability evaluation of mobile systems,'' *Int. J. Hum.-Comput. Stud.*, vol. 60, nos. 5–6, pp. 599–620, 2004. doi: 10.1016/j.ijhcs.2003.11.001.

[16] J. Nielsen. (1995). 10 Usability Heuristics for User Interface Design. Nielsen Norman Group. Accessed: Jun. 5, 2018. [Online]. Available: https://www.nngroup.com/articles/ten-usability-heuristics/

[17] R. Harrison, D. Flood, and D. Duce, "Usability of mobile applications: Literature review and rationale for a new usability model," *J. Interact. Sci.*, vol. 1, no. 1, p. 1, 2013. doi: 10.1186/2194-0827-1-1.
[18] A. S. Ajibola and L. Goosen, "Development of heuristics for usability evaluation of M-commerce applications," in *Proc. South African Inst. Comput. Sci. Inf. Technol. (SAICSIT)*, Thaba 'Nchu, South Africa, Sep. 2017, pp. 3:1–3:10. doi: 10.1145/3129416.3129428.
[19] D. D. Salvucci, "Predicting the effects of in-car interface use on driver performance: An integrated model approach," *Int. J. Hum.-Comput. Stud.*, vol. 55, no. 1, pp. 85–107, 2001. doi: 10.1006/ijhc.2001.0472.
[20] B. Bonifácio, D. Viana, S. R. C. Vieira, C. Araújo, and T. Conte, "Applying usability inspection techniques to evaluate mobile applications," in *Proc. 9th Symp. Hum. Factors Comput. Syst. (IHC)*, Belo Horizonte, Brazil, Oct. 2010, pp. 189–192.
[21] J. Heo, D.-H. Ham, S. Park, C. Song, and W. C. Yoon, "A framework for evaluating the usability of mobile phones based on multi-level, hierarchical model of usability factors," *Interact. Comput.*, vol. 21, no. 4, pp. 263–275, 2009. doi: 10.1016/j.intcom.2009.05.006.
[22] R. Inostroza, C. Rusu, S. Roncagliolo, C. Jiménez, and V. Rusu, "Usability heuristics validation through empirical evidences: A touchscreen-based mobile devices proposal," in *Proc. 31st Int. Conf. Chilean Comput. Sci. Soc. (SCCC)*, Nov. 2012, pp. 60–68. doi: 10.1109/SCCC.2012.15.
[23] Y. S. Lee, S. W. Hong, T. L. Smith-Jackson, M. A. Nussbaum, and K. Tomioka, "Systematic evaluation methodology for cell phone user interfaces," *Interact. Comput.*, vol. 18, no. 2, pp. 304–325, 2006. doi: 10.1016/j.intcom.2005.04.002.
[24] G. Schiefer and M. Decker, "Taxonomy for mobile terminals—A selective classification scheme," in *Proc. Int. Conf. e-Bus. (ICE-B)*, Porto, Portugal, Jul. 2008, pp. 255–258. doi: 10.5220/0001911502550258.
[25] K. Sagar and A. Saha, "A systematic review of software usability studies," *Int. J. Inf. Technol.*, vol. 3, pp. 1–24, Dec. 2017. doi: 10.1007/s41870-017-0048-1.
[26] B. Shackel and S. J. Richardson, *Human Factors for Informatics Usability*. Cambridge, U.K.: Cambridge Univ. Press, 1991.
[27] J. Nielsen, "Usability Engineering," in *The Computer Science and Engineering Handbook*. Amsterdam, The Netherlands: Elsevier, 1997, pp. 1440–1460.
[28] P. A. Silva, K. Holden, and P. Jordan, "Towards a list of heuristics to evaluate smartphone apps targeted at older adults: A study with apps that aim at promoting health and well-being," in *Proc. 48th Hawaii Int. Conf. Syst. Sci. (HICSS)*, Kauai, HI, USA, Jan. 2015, pp. 3237–3246. doi: 10.1109/HICSS.2015.390.
[29] V. S. M. Paixão-Cortes, M. Dos Santos da Silva Tanus, W. R. Paixão-Cortes, O. N. de Souza, M. De Borba Campos, and M. S. Silveira, "Usability as the key factor to the design of a Web server for the cref protein structure predictor: The wcref," *Information*, vol. 9, no. 1, p. 20, 2018. doi: 10.3390/info9010020.
[30] J. Bergman and J. Vainio, "Interacting with the flow," in *Proc. 12th Conf. Hum.-Comput. Interact. Mobile Devices Services (MobileHCI)*, Lisbon, Portugal, Sep. 2010, pp. 249–252. doi: 10.1145/1851600.1851641.
[31] F. Botella, J. A. Gallud, and R. Tesoreiro, "Using interaction patterns in heuristic evaluation," in *Proc. 1st Int. Conf. Design, User Exper., Usability (DUXU)*, Orlando, FL, USA, Jul. 2011, pp. 23–32. doi: 10.1007/978-3-642-21675-6_3.
[32] M. Memedi, G. Tshering, M. Fogelberg, I. Jusufi, E. Kolkowska, and G. Klein, "An interface for IoT: Feeding back health-related data to Parkinson's disease patients," *J. Sens. Actuator Netw.*, vol. 7, no. 1, p. 14, 2018. doi: 10.3390/jsan7010014.
[33] J. Nielsen. (1994). *How to Conduct a Heuristic Evaluation*. [Online]. Available: https://www.nngroup.com/articles/how-to-conduct-a-heuristic-evaluation/
[34] M. A. D. Dourado and E. D. Canedo, "Usability heuristics for mobile applications—A systematic review," in *Proc. 20th Int. Conf. Enterprise Inf. Syst. (ICEIS)*, Funchal, Portugal, vol. 2, Mar. 2018, pp. 483–494. doi: 10.5220/0006781404830494.
[35] S. Feinberg and M. Murphy, "Applying cognitive load theory to the design of Web-based instruction," in *Proc. IEEE Prof. Commun. Soc. Int. Prof. Commun. Conf. 18th Annu. ACM Int. Conf. Comput. Document., Technol. Teamwork*, Cambridge, MA, USA, Sep. 2000, pp. 353–360. doi: 10.1109/IPCC.2000.887293.
[36] B. Schildbach and E. Rukzio, "Investigating selection and reading performance on a mobile phone while walking," in *Proc. 12th Conf. Hum.-Comput. Interact. Mobile Devices Services (MobileHCI)*, Lisbon, Portugal, Sep. 2010, pp. 93–102. doi: 10.1145/1851600.1851619.
[37] N. Ahmad, A. Rextin, and U. E. Kulsoom, "Perspectives on usability guidelines for smartphone applications: An empirical investigation and systematic literature review," *Inf. Softw. Technol.*, vol. 94, pp. 130–149, Feb. 2018. doi: 10.1016/j.infsof.2017.10.005.
[38] D. S. K. Seong, "Usability guidelines for designing mobile learning portals," in *Proc. 3rd Int. Conf. Mobile Technol., Appl. Syst. (Mobility)*, Bangkok, Thailand, Oct. 2006, Art. no. 25. doi: 10.1145/1292331.1292359.
[39] B. Fetaji, M. Fetaji, and K. Kaneko, "Comparative study of efficiency among the developed MLUAT methodology in comparison with qualitative user testing method and heuristics evaluation," in *Proc. 33rd Int. Conf. Inf. Technol. Interfaces (ITI)*, Jun. 2011, pp. 269–274.
[40] J. Pitkänen, "Mobile application usability research—Case study of a video recording and annotation application," Bachelor Eng. Degree Programme Media Eng., Helsinki Metr. Univ. Appl. Sci., Helsinki, Finland, 2016.
[41] R. M. Miranda, "Analysis of the usability of mobile device applications based upon heuristics," M.S. thesis, Inst. Comput. Sci., Univ. Inf. Soc., Tokyo, Japan, 2014.
[42] R. Y. Gómez, D. C. Caballero, and J.-L. Sevillano, "Heuristic evaluation on mobile interfaces: A new checklist," *Sci. World J.*, vol. 2014, Aug. 2014, Art. no. 434326. doi: 10.1155/2014/434326.
[43] B. Kitchenham, "Procedures for performing systematic reviews," Dept. Comput. Sci., Keele Univ., Keele, U.K., 2004, vol. 33, no. 2004, pp. 1–26.
[44] K. R. Felizardo, E. Y. Nakagawa, S. C. P. F. Fabbri, and F. C. Ferrari, *Systematic Review of Software Engineering Literature: Theory and Practice*. Brasilia, Brazil: Elsevier, 2017, p. 144.
[45] S. Fabbri, C. Silva, E. Hernandes, F. Octaviano, A. Di Thommazo, and A. Belgamo, "Improvements in the StArt tool to better support the systematic review process," in *Proc. 20th Int. Conf. Eval. Assessment Softw. Eng.*, 2016, Art. no. 21.
[46] F. S. Silva, F. S. F. Soares, A. L. Peres, I. M. de Azevedo, A. P. L. F. Vasconcelos, F. K. Kamei, and S. R. de Lemos Meira, "Using CMMI together with agile software development: A systematic review," *Inf. Softw. Technol.*, vol. 58, pp. 20–43, Feb. 2015. doi: 10.1016/j.infsof.2014.09.012.
[47] C. Wohlin, "Guidelines for snowballing in systematic literature studies and a replication in software engineering," in *Proc. 18th Int. Conf. Eval. Assessment Softw. Eng. (EASE)*, London, U.K., May 2014, pp. 38:1–38:10. doi: 10.1145/2601248.2601268.
[48] O. M. Neto and M. da Graça Pimentel, "Heuristics for the assessment of interfaces of mobile devices," in *Proc. 19th Brazilian Symp. Multimedia Web (WebMedia)*, Salvador, Brazil, Nov. 2013, pp. 93–96. doi: 10.1145/2526188.2526237.
[49] R. Inostroza, C. Rusu, S. Roncagliolo, V. Rusu, and C. A. Collazos, "Developing SMASH: A set of SMArtphone's uSability heuristics," *Comput. Standards Interfaces*, vol. 43, pp. 40–52, Jan. 2016. doi: 10.1016/j.csi.2015.08.007.
[50] S. R. Humayoun, P. H. Chotala, M. S. Bashir, and A. Ebert, "Heuristics for evaluating multi-touch gestures in mobile applications," in *Proc. 31st Int. BCS Hum. Comput. Interact. Conf. (HCI)*. Sunderland, U.K.: Univ. of Sunderland, Jul. 2017, Art. no. 89. doi: 10.14236/ewic/HCI2017.89.
[51] G. Joyce and M. Lilley, "Towards the development of usability heuristics for native smartphone mobile applications," in *Proc. 3rd Int. Conf. Design, User Exper., Usability (DUXU)*, Heraklion, Greece, Jun. 2014, pp. 465–474. doi: 10.1007/978-3-319-07668-3_45.
[52] M. Billi, L. Burzagli, T. Catarci, G. Santucci, E. Bertini, F. Gabbanini, and E. Palchetti, "A unified methodology for the evaluation of accessibility and usability of mobile applications," *Universal Access Inf. Soc.*, vol. 9, no. 4, pp. 337–356, 2010. doi: 10.1007/s10209-009-0180-1.
[53] A. S. Ajibola and L. Goosen, "Development of heuristics for usability evaluation of m-commerce applications," in *Proc. South African Inst. Comput. Sci. Inf. Technol. (SAICSIT)*, Thaba Nchu, South Africa, Sep. 2017, pp. 3:1–3:10. doi: 10.1145/3129416.3129428.
[54] P. A. Silva, K. Holden, and A. Nii, "Smartphones, smart seniors, but not-so-smart apps: A heuristic evaluation of fitness apps," in *Proc. 8th Int. Conf. Augmented Cognition*, Heraklion, Greece, Jun. 2014, pp. 347–358. doi: 10.1007/978-3-319-07527-3_33.
[55] R. Likert, "A technique for the measurement of attitudes," Ph.D. dissertation, Sci. Press, Arch. Psychol., New York, NY, USA, 1932, no. 140.

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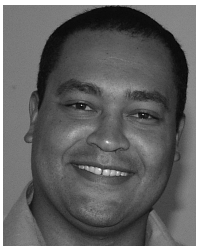

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