How to develop usability heuristics: A systematic literature review

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A B S T R A C T

Numerous sets of usability heuristics have been designed for specific domains, as traditional heuristics do not evaluate the specific features of particular applications. A substantial portion of the existing research focuses on designing new sets of heuristics, demonstrating the interest in heuristics that might identify specific usability problems for specific application domains. This article presents an exhaustive review of 73 studies related to usability heuristics for specific domains and methodologies; the objective is to identify the approach that is used to create usability heuristics and whether a formal and systematic process is involved. We conducted a systematic literature review of papers published between 2006 and 2016. The review was based on the guidelines proposed by Kitchenham (2007) [13] and shows that most studies use an informal process to develop usability heuristics. The creation of heuristics is mainly based on existing heuristics, literature reviews, usability problems, and guidelines. However, a few studies apply a methodology to define, validate and refine the set of heuristics proposed. Nevertheless, these methodologies should be formalized in order to help the process of creating usability heuristics.

1. Introduction

Usability is typically defined as the "capability of being used", in other words, the capability of an entity to be used [1]. Usability can be designed into the product and can be evaluated by usability inspections or usability tests. Heuristic evaluation is a usability inspection method widely used to find usability problems. This method uses "heuristic principles" or "usability heuristics" to evaluate usability.

Several authors have designed new sets of usability heuristics for specific domains, as generic or traditional heuristics do not evaluate specific features of different types of software and applications. The majority of existing research focuses on designing new sets of heuristics, which indicates the need to evaluate usability efficiently and effectively based on heuristics. In this sense, it is important to know how the authors developed the new heuristics and if the methodologies they used make it possible to create and validate usability heuristics.

This paper presents a systematic review of the processes followed to develop and specify usability heuristics along with methodologies that have been proposed to develop usability heuristics. It also aims to identify the different approaches used to create usability heuristics and to determine how many studies use a well-defined methodology to establish heuristics.

The article is organized as follows: Section 2 introduces the main concepts related to usability, heuristic evaluation, usability heuristics, and the process used to develop usability heuristics; in addition, it explores related work regarding methodologies to create usability heuristics. Section 3 refers to the review questions. Section 4 presents the protocol used for the systematic literature review. Section 5 presents the selected studies. Section 6 describes the results of the systematic review. Section 7 discusses the results. Finally, Section 8 presents our conclusions.

2. Background

The concepts of usability, heuristic evaluation and usability heuristics are presented below. In addition, we discuss the research problem. Finally, related work and the approaches that exist to establish usability heuristics are described.

2.1. Usability

Standard ISO 9241-11 has been successful in providing an internationally accepted definition about what is usability and its application in several fields [1]. This standard defines usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [2].

There are several terms related to usability. These concepts are important when evaluating usability. The ISO standard defines these

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terms as follows [2]:

- "User: person who interacts with the product,
- Goal: intended outcome,
- Effectiveness: accuracy and completeness with which users achieve specified goals,
- Efficiency: resources expended in relation to the accuracy and completeness with which users achieve goals,
- Satisfaction: freedom from discomfort and positive attitudes toward the use of the product,
- Context of use: users, tasks, equipment (hardware, software and materials), and the physical and social environments in which a product is used" [2].

However, "a generally accepted usability definition still does not exist, as its complex nature is hard to describe in one definition" [3].

The ISO 9241-11 standard is still under review that incorporates what has been learned about usability since 1998 and what new elements have emerged in relation to the concept of usability [1].

2.2. Heuristic evaluation

There are many inspection and test methods that make it possible to measure/evaluate usability. One of these methods is heuristic evaluation, an inspection method that identifies usability problems based on usability principles or usability heuristics.

Heuristic evaluation was proposed by Nielsen and Molich [4] and involves usability experts who inspect a product interface based on heuristics and identify usability problems. These problems are associated with usability heuristics, and then the frequency, severity and criticality of each problem are evaluated. It is recommended that three to five experts perform a heuristic evaluation [5].

First, each expert evaluator judges the product interface separately and prepares an individual list of usability problems based on a set of usability heuristics. Then, they work together and generate a unique list of usability problems.

Next, each evaluator independently qualifies the problems encountered in terms of frequency, severity and criticality. Finally, the results are collected and summarized in a single report. This report describes the usability problems found, and may suggest solutions that help designers to improve the product [6].

To qualify the usability problems, three scales are used:

1. Severity scale: the severity of the identified usability issue. Thus, it is possible to detect problems that prevent the proper functioning of the product interface.
2. Frequency scale: the degree of occurrence of the identified usability issue. Thus, it is possible to know what problems are most common or recurrent within the product interface.
3. Criticality scale: the sum of the severity and frequency. Thus, it is possible to determine which problems are the most critical so that they can be corrected as soon as possible.

On the one hand, the advantages of performing a heuristic evaluation are: (1) It is less expensive compared to other methods in terms of time, number of usability experts and resources; (2) it does not require extensive planning; (3) it is applicable in the early stages of software development (from paper prototypes to executable systems); (4) it is possible to find many problems (critical and less critical); and (5) it not involves users [4,5].

On the other hand, the disadvantages of performing a heuristic evaluation are: (1) Evaluators must have experience and adequate knowledge to evaluate the product interface; (2) evaluators may not understand the tasks performed by the product, so it can be difficult to identify usability problems; and (3) usability problems are identified without directly giving an idea of how to solve it (there is no systematic

Table 1
Nielsen's 10 usability heuristics.

Id	Name
H1	Visibility of system status
H2	Match between system and the real world
H3	User control and freedom
H4	Consistency and standards
H5	Error prevention
H6	Recognition rather than recall
H7	Flexibility and efficiency of use
H8	Aesthetic and minimalist design
H9	Help users recognize, diagnose, and recover from errors
H10	Help and documentation

way to generate solutions to the problems encountered) [4,6].

2.3. Usability heuristics

An interface inspection by heuristic evaluation is based on a set of usability heuristics. They are called "heuristics" because they are more in the nature of rules of thumb than specific usability guidelines [7]. Nielsen's 10 heuristics are widely recognized. The set of Nielsen's heuristics is shown in Table 1. These heuristics are presented as they were created by the same authors who proposed heuristic evaluation as a usability inspection method [4].

Each system, software and/or application has features that differentiate them. Thus, traditional heuristics – aimed to evaluate traditional user interfaces – might not evaluate certain unique features for specific domains, ignoring important elements to consider when evaluating usability.

Therefore, several authors have designed new sets of usability heuristics, modifying Nielsen's heuristics and/or adding new heuristics to evaluate specific aspects not covered by other heuristics. Appendix A shows a review of several sets of usability heuristics created for specific domains by different authors.

2.4. The process to develop usability heuristics

Several studies have developed different sets of usability heuristics for evaluating specific domains and their specific features. However, in most of the reviewed articles, there is no evidence that a methodology had been used in order to develop usability heuristics; there are no theories or appropriate models to establish usability heuristics for specific domains or to evaluate the usability heuristics in terms of applicability to specific domains. Most existing heuristics have been developed on the basis of the researchers' extensive experience or by adapting methods usually employed for other purposes [34].

In general, it is possible to encompass the development process of usability heuristics in two stages: (1) extract information, and (2) transform the information extracted into heuristics [8]. Nevertheless, there is no consensus about the most effective process for developing heuristics for specific application domains [9].

There are different approaches to developing usability heuristics. Each approach follows a different process. We refer to "process" as the steps or activities needed to create usability heuristics. In addition, we refer to "methodology" as a formal and systematic process to create usability heuristics. A methodology includes steps or activities to create heuristics, but 1) these steps are formally defined; and 2) a systematic process is followed to create heuristics. There are formal processes (follow formal and systematic steps, i.e., use a methodology) and informal processes (follow steps and perform activities in a non-systematic way).

Many proposals of usability heuristics are established as an extension or adaptation of existing heuristics (such as Nielsen's heuristics). The studies do no document or explain in detail the

approach followed to create the new set of usability heuristics. Most studies do not specify whether the process followed is informal, formal, or if the authors used a methodology.

Even though there is a methodology that supports the process for developing usability heuristics [31], there is currently no clear protocol for heuristics' validation. The whole process of developing usability heuristics has yet to be formalized [48]. In conclusion, there is no formal process to formulate, specify, validate and refine usability heuristics.

2.5. Related work

Sim, Read and Cockton [9] argue that there are two main research areas related to heuristics: on the one hand the analysis of methods to improve the efficiency of heuristics and, on the other hand, the development of heuristics for specific domains.

The literature shows that there is no specific method for developing heuristics or which approach is more appropriate to establish them. Authors follow different and diverse processes to define, specify and validate their new set of heuristics.

Paddison and Englefield [10] propose two methods for developing heuristics: (1) explore the literature; and (2) analyze the data from previous studies. However, the authors do not clarify the meaning of analyzing the data from previous studies, which could be interpreted as performing primary research or conducting a meta-analysis of other researchers' results [9].

Furthermore, Ling and Salvendy [11] suggest three methods for establishing heuristics: (1) review and highlight previous research; (2) modify or adapt existing heuristics (e.g., Nielsen's heuristics); and (3) base them on empirical data. Nevertheless, reviewing the literature, we found other processes to create usability heuristics, so the methods suggested by the authors are not the only methods used.

Jaferian et al. [12] declare that two approaches can be used to develop specific heuristics:

1. A bottom-up approach: Qualitative data are collected and analyzed to understand the characteristics of the domain, and then heuristics are created using real-world data. The heuristics reflect real problems but are limited by the scope and richness of the qualitative data and the interpretation of that data by the researchers.
2. A top-down approach: Theories or existing heuristics are used by experts to create the new set of heuristics. This approach relies on expert knowledge to modify a theory or existing heuristics. Hence, the process of heuristic derivation is prone to researcher bias.

To avoid the limitations of each approach, a more rigorous process can be used by combining both bottom-up and top-down approaches to create heuristics. The process can start adopting a bottom-up approach to collect empirical data by using qualitative data analysis, and then a top-down approach can be used to justify, support, and combine the identified heuristics into a new set of heuristics [12].

Hermawati and Lawson [8] performed a systematic literature review of the processes used to develop usability heuristics; the methods used to validate the new set of heuristics; and the effectiveness of the new set of heuristics. The authors argue that the creation of usability heuristics consist of two steps: (1) extract information; and (2) convert the extracted information into heuristics.

For the first step, they observed four different methods to extract information: (1) Those based on theories; (2) those based on the literature; (3) those based on users and the context of use; and (4) those based on usability issues and/or existing heuristics/guidelines.

Even though the authors conducted a review of the different approaches that have been used to develop usability heuristics, the main objective of their research was to analyze the methods used to validate new sets of usability heuristics and the effectiveness of the new sets of heuristics to detect usability problems.

The literature was reviewed in order to identify whether a formal process has been proposed to create usability heuristics. The review shows that there is no consensus on which approach is more effective to develop a specific heuristics domain. In addition, we have not identified whether authors use a systematic process to develop, validate and refine their usability heuristics.

We aim to cover the whole development process of usability heuristics, clearly identifying all the stages to be followed to formulate, specify, validate and refine the new set of heuristics.

We perform a systematic review of the literature in order to identify: (1) how different studies develop usability heuristics; and (2) which approaches or methodologies are used for their creation and validation.

3. Research questions

Due to the need to effectively evaluate the usability of specific application domains, several authors have developed studies in order to establish usability heuristics. In this regard, it is important to know which approaches the authors use to develop new heuristics and if the approaches used allow creating and validating usability heuristics correctly. The sets of heuristics should be well designed, should help to assess effectively and efficiently the usability of specific application domains and should be useful and easy to use for the evaluators. In Table 2, we describe the research questions used to conduct the systematic literature review.

4. Research method

We have carried out a systematic literature review using the approach suggested by Kitchenham [13]. The review process involved three stages with several activities:

1. Planning the review: to define the need for a systematic review; to raise the research questions; and to define the review protocol: data sources, search strategy and terms, study selection criteria, quality of the studies, data extraction and data synthesis.
2. Conducting the review: to select and review studies; to answer the research questions; and to present the results, discussions and conclusions.
3. Reporting the review: to write up the results of the review and format the final document.

The research method and activities performed are described below.

4.1. Data sources

The electronic database sources used in this review included those identified as relevant to information; technology; engineering; and computer science: (1) Science Direct; (2) ACM Digital Library; (3) IEEE Xplore Digital Library; (4) Springer Link; (5) Scopus; and (6) Google Scholar. Articles of the last 10 years were reviewed (from January 2006 to April 2016).

Table 2
Research questions for the systematic review.

ID	Research Question
RQ1	How are the usability heuristics developed?
RQ2	Are there methodologies to establish usability heuristics?
RQ3	If there are methodologies to establish usability heuristics, do these methodologies propose a formal and systematic process to specify and validate usability heuristics?

Table 3
Search strings.

No	Search strings
1	("usability heuristics" OR "usability heuristic") AND (methodology OR design OR "formal process" OR process) AND ("heuristic evaluation")
2	("usability heuristic" OR "usability heuristics" OR "usability guidelines") AND (methodology OR design OR "formal process" OR "heuristic evaluation")
3	("usability heuristics" OR "usability heuristic") AND (methodology OR design OR "formal process" OR process)
4	(usability) AND (heuristics) AND ("usability heuristics") AND (process OR developing OR methodology OR "formal methodology" OR "formal process" OR "informal process" OR "developing usability heuristics" OR design OR "usability design" OR create)
5	(heuristic OR heuristics OR pattern) AND (usability) AND (methodology OR "design process" OR "heuristic evaluation")

4.2. Search strategy and terms

The search terms included "usability" and "heuristic", in addition to the combination of them as "usability heuristic" and "usability heuristics". In addition, we used terms related to processes or methods used to develop usability heuristics, for example, "process", "formal process", "methodology" and "design". Finally, we added terms related to inspections methods that use heuristics, for example, "heuristic evaluation". The detailed search strings used are presented in Table 3.

4.3. Study selection criteria

A number of different criteria were specified to select appropriate studies for inclusion and exclusion in/from the review. The studies that met the following conditions were included:

1. Research papers.
2. Studies that contain propositions for usability heuristics in a specific domain.
3. Studies that propose an approach, process or methodology to establish usability heuristics.
4. Studies published between January 2006 and April 2016.
5. Papers written in English, Spanish or Portuguese.

The following types of papers were excluded:

1. Studies that contain heuristics proposed for other aspects (e.g., aesthetics, automation, hyper-heuristics).
2. Studies that do not explain how the usability heuristics were developed.
3. Theses (e.g., master' theses) that have not been published.
4. Articles not focused primarily on the definition of usability heuristics, such as reports on usability case studies or usability tests.

4.4. Quality of the studies

To assess the quality of the studies (i.e., which studies minimize bias and maximize internal and external validation), we evaluated the quality of the information presented in terms of:

1. Articles describing in detail the usability heuristics developed and the approach used to create heuristics.
2. Articles that follow a clear process and are based on credible elements to develop heuristics.
3. Articles presenting well-designed heuristics, with sufficient information to understand them.
4. Articles that adequately document the activities performed to create the heuristics.

The quality score was used to assist primary study selection. The quality data were used to investigate whether the results of the primary study were associated with study quality.

4.5. Data extraction

For each study included in the review that was related to the development of usability heuristics, we identified and extracted information regarding the following five elements:

1. The authors and year of a study.
2. The domain of the proposed usability heuristics.
3. How the heuristics were developed (based on the approach, steps or methodology used in the study).
4. The template used to specify the proposed usability heuristics.
5. The validation method used to validate the proposed usability heuristics (if the heuristics were validated).

For each study included in the review that was related to approaches or methodologies to develop usability heuristics, we identified and extracted information regarding the following four elements:

1. The authors and year of the study.
2. The stages, steps or phases defined to develop usability heuristics.
3. The tasks or activities of each stage, step or phase.
4. The number of studies that have used a methodology to develop usability heuristics.

4.6. Data synthesis

The extracted information about the studies was grouped, summarized and tabulated in eight separate tables based on the different approaches to developing usability heuristics. Each table is shown in a different appendix. Appendix B shows the studies that created usability heuristics based on existing heuristics; Appendix C details heuristics developed based on methodologies; Appendix D presents heuristics established based on literature reviews; Appendix E shows heuristics created based on usability problems; Appendix F details heuristics developed based on a mixed process; Appendix G presents heuristics established based on guidelines or design principles/recommendations; Appendix H shows heuristics created based on interviews; and Appendix I details heuristics developed based on theories.

Each table summarizes an overview of each study, detailing: (1) the authors; (2) year of the study; (3) domain of the proposed usability heuristics; (4) steps followed to develop usability heuristics; (5) format or template used to specify heuristics; and (6) evaluation method used to validate the set of heuristics (if heuristics were validated). An additional table summarizes all reviewed studies that proposed usability heuristics (Appendix A).

Furthermore, the extracted information about the studies related to approaches or methodologies to develop usability heuristics is tabulated in a table that includes: (1) the authors; (2) year of the study; (3) methodology's name; (4) stages or phases in the methodology, with its respective tasks or activities; and (5) studies that have used the methodology to develop usability heuristics.

Finally, all information collected is analyzed in Section 6 (Results), including tables and figures that summarize and explain the results.
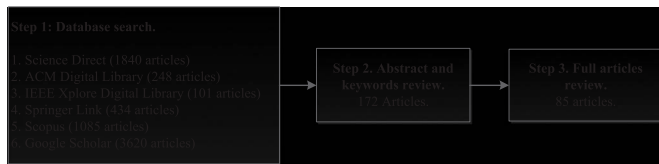
Fig. 1. Flow diagram with the results of the articles selection process.

Table 4
Papers selected using the inclusion criteria.

Type of study	Number of studies
Studies related to developing usability heuristics for a specific domain	68
Studies related to processes or methodologies to develop usability heuristics	7
Total	73 studies[a]

[a] Two studies include methodologies, but also the sets of usability heuristics that were created. For this reason, there are 73 studies (and not 75, which would be the result of adding 7 to 68).

5. Study selection

Using the defined inclusion criteria, a total of 73 studies (based on 85 articles) were identified as relevant to the current review. Some articles document different stages of the same research; for this reason, we refer to 73 studies, but based on 85 articles. Fig. 1 provides a flow diagram documenting the results of the study selection process.

Table 4 shows the number of papers that met the inclusion criteria. A total of 68 papers were review related to usability heuristics for specific domains; a total of 7 papers were reviewed related to methodologies to develop usability heuristics.

Eighty-seven studies were excluded using the exclusion criteria because the articles are beyond the scope of this review.

6. Results

This section summarizes the results obtained after conducting the systematic review. The analysis of the results focuses on answering RQ1 and RQ2 research questions shown in Section 3. As the RQ3 research question is considered the most critical one, its response is discussed in Section 7.

6.1. Approaches to developing usability heuristics (RQ1 and RQ2)

Based on the review of the studies, we note that most authors do not use a formal methodology to develop their new set of usability heuristics (75% of studies), but they use steps or sequential activities to establish heuristics. Table 5 shows the different approaches to developing usability heuristics that we identified in the review.

Table 5
How usability heuristics are created.

| Heuristics are created based on	Amount of studies	%
1. Existing heuristics	17 studies	25.00%
2. Methodologies	17 studies	25.00%
3. Literature reviews	9 studies	13.24%
4. Usability problems	9 studies	13.24%
5. Mixing processes	6 studies	8.82%
6. Guidelines, principles or design recommendations	5 studies	7.35%
7. Interviews	3 studies	4.41%
8. Theories	2 studies	2.94%
Total	68 studies	100%
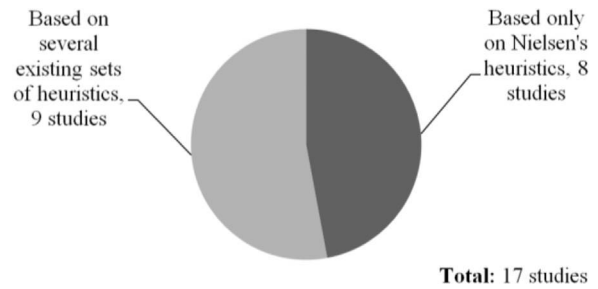
Fig. 2. New set of usability heuristics based on existing heuristics.

6.1.1. Establishing new set of usability heuristics based on existing heuristics

17 studies used existing sets of usability heuristics to develop new heuristics. Typically, the activities of most authors when creating heuristics are as follows:

1. Collect information about existing heuristics and point out its limitations for evaluating the usability of a specific domain.
2. Explore information and features of a specific domain that should be considered in the development of new heuristics.
3. Propose the new set of heuristics using different templates.

To develop new sets of usability heuristics, 8 studies are based only on Nielsen's heuristics [14–21], whereas the remaining 9 studies are based on several sets of heuristics (including Nielsen's heuristics) to develop the new sets of heuristics [22–30] (see Fig. 2).

Appendix B provides details on the analyzed studies: authors, domains in which specific heuristics were proposed and how they were defined, specified (template) and validated.

6.1.2. Establishing new set of usability heuristics based on methodologies

17 studies used a specific methodology to develop new heuristics. After reviewing the literature, 7 methodologies were found to establish usability heuristics. Of these, four were methodologies proposed to establish heuristics for specific domains (Rusu et al. [31], Van Greunen et al. [32], Hermawati and Lawson [33], and Lechner et al. [34]). Two methodologies were designed as part of the study that establishes heuristics for the specific domain (Hub and Čapková [35] and Franklin et al. [36]). Finally, one methodology oriented to designing guidelines was adapted by one study in order to establish new usability heuristics (Hevner et al. [37]). Table 6 presents a summary of the methodologies reviewed.

Out of 7 revised methodologies, only 5 were used to create usability heuristics (see Fig. 3). Of these, the methodology proposed by Rusu et al. [31] was used in 13 of the 17 studies reviewed. This shows that authors of the 13 studies were trying to follow a formal process to develop and validate the new set of heuristics.

Table 7 shows the studies that used each methodology. In addition, Table 8 shows the methodology used in each of the 17 studies reviewed. Appendix C provides details on the analyzed studies and the methodology used.

6.1.3. Establishing new set of usability heuristics based on literature reviews

9 studies reviewed the literature identifying concepts, specific characteristics of the domains, existing heuristics and other relevant elements to develop new usability heuristics.

The typical steps followed by most authors to create new heuristics are:

1. Review the literature to:

1.1. Collect information about usability, existing heuristics, features of specific domain and previous studies; or

Table 6
Methodologies reviewed.

Methodology name	Authors	Steps and activities
A Methodology to Establish Usability Heuristics	Rusu et al. (2011) [31]	Six stages that may be applied iteratively: Exploratory; Descriptive; Correlational; Explicative; Validation; and Refinement stage.
A Three-phase Process to Develop Heuristics	Van Greunen et al. (2011) [32]	Three phases that can be applied iteratively: Design; Validation; and Application/Usage.
A User-Centric Methodology to Establish Usability Heuristics for specific domains	Hermawati and Lawson (2015) [33]	Two stages with several activities: (1) How to expand heuristics sets for a specific domain and (2) How to validate heuristics sets for a specific domain.
User Involvement in Developing Usability Heuristics	Lechner et al. (2013) [34]	Two phases with several activities: (1) Collaborative group session with experts and (2) Validation of heuristics with actual users. Finally a comparative analysis of results.
Methodology of Heuristics Creation	Hub and Čapková (2010) [35]	Seven steps: Basic set of heuristics; Specification of requirements on resources; Environment analysis; Preparation of heuristics creation; Heuristics creation; Evaluation of heuristics; and Final proposal.
Methodology to adapt usability heuristics	Franklin et al. (2014) [36]	Nine steps: Review; Elimination; Group similar; Fusion similar; Grouping and Adaptation; Preliminary resettlement and adaptation; Focus Group; Final Result; and Validate the set of heuristics.
Guidelines for Design Science in Information Systems Research	Hevner et al. (2004) [37]	Seven guidelines: Design as an Artifact; Problem Relevance; Design Evaluation; Research Contributions; Research Rigor, Design as a Search Process; and Communication of Research.

1.2. Understand how existing heuristics can be applied to evaluate a specific domain.

2. Define the new set of usability heuristics.

3. Validate the set of heuristics. The methods used to validate the heuristics are varied. Some of them are: heuristic evaluation, expert opinion, scenarios, thinking aloud and questionnaires.

Out of 9 studies, only 3 studies conducted a systematic literature review to collect information about existing heuristics, features of specific domain, previous studies, etc. [53–55]. Most studies (6 studies) only performed a limited literature review to gather information [56–61].

Furthermore, out of 9 studies, 7 carried out a validation of the set of usability heuristics proposed [53,55–60]. In addition, 3 studies (out of 6 studies that applied a validation method) performed a refinement of the set of heuristics [57,58,60], improving them based on the results obtained during the validation step (see Fig. 4).

Table 9 shows what type of review was performed in each study, whether a validation method was applied and whether a refinement to the set of heuristics was performed. Appendix D provides details on the analyzed studies.

6.1.4. Establishing new set of usability heuristics based on usability problems

9 studies were based on usability problems to develop new usability heuristics. Typical activities of most authors include the following:

1. Identify and analyze usability problems of specific domains through

1.1. Usability evaluations (e.g., heuristic evaluation, user test, questionnaire, interview, among others); or

1.2. Previous studies that documented usability problems related to a specific domain.

Table 7
Studies that applied each methodology.

Methodology	Number of studies	Studies
Rusu et al. [31]	13	[38–50]
Van Greunen et al. [32]	1	[51]
Hub and Čapková [35]	1	[35]
Hevner et al. [37]	1	[52]
Franklin et al. [36]	1	[36]
Hermawati and Lawson [33]	0	–
Lechner et al. [34]	0	–

2. Develop a set of categories that group similar usability problems.

3. Create usability heuristics that describe how usability problems can be resolved or avoided. Four studies (out of 9 studies) [62–65] also analyzed Nielsen's heuristics to evaluate which heuristics are relevant for assessing the usability of the specific domain.

Obtaining and analyzing usability problems differ among the studies reviewed. For instance, Bertini et al. [62] collected usability problems from previous studies, and then three experts analyzed and refined the problems gathered. Next, each researcher worked individually, assessing which of Nielsen's heuristics were considered relevant and irrelevant for the specific domain (and if necessary, some revision or modification) and which additional heuristics needed to be included.

Furthermore, Petri and Power [66] identified usability problems evaluating 3 products through a think-aloud protocol; after that, they evaluated an additional 6 products based on expert opinion.

Table 10 shows the steps followed by each study to develop the new set of heuristics. Each step is listed from 1 to 8 in each row of the table. Some studies share some steps, while others do not. Details on the analyzed studies are presented in Appendix E.
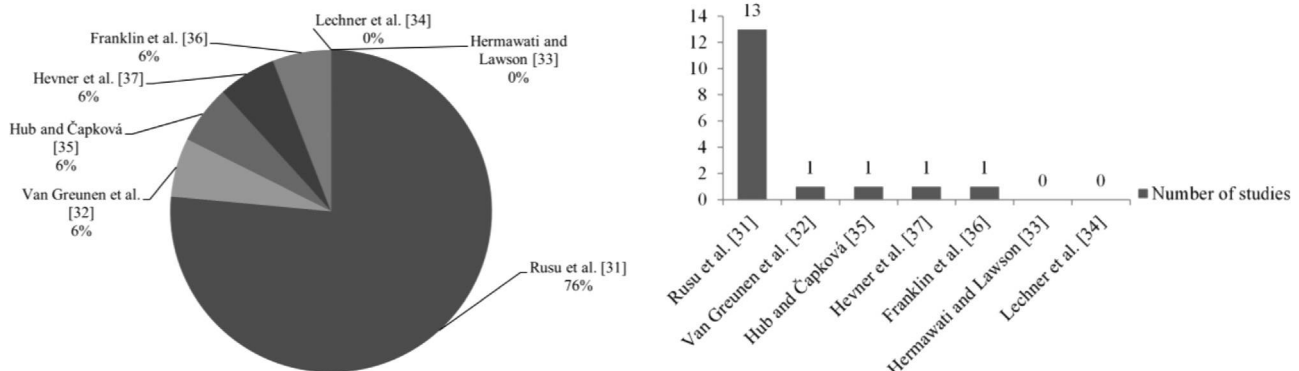

Fig. 3. Percentage and number of studies that use each methodology.

Table 8
Methodology used in each of the 17 studies reviewed.

| N°	Domain	Methodology used
1	Public administration portal [35]	Hub and Čapková [32]
2	Grid Computing [38]	Rusu et al. [31]
3	Virtual worlds [39]	Rusu et al. [31]
4	Health social networking websites [51]	Van Greunen et al. [32]
5	Interactive Digital Television [40]	Rusu et al. [31]
6	Heuristics with cultural aspects [41]	Rusu et al. [31]
7	Social networks [42]	Rusu et al. [31]
8	TV Emotion [43]	Rusu et al. [31]
9	Multimodal interfaces on tablets applications [44]	Rusu et al. [31]
10	Mobile interfaces [45]	Rusu et al. [31]
11	Touch and gesture interaction [52]	Hevner et al. [37]
12	Collaborative Augmented Reality Remote Systems (CARRS) [36]	Franklin et al. [36]
13	Transactional websites [46]	Rusu et al. [31]
14	Wearable Augmented Reality Applications [47]	Rusu et al. [31]
15	Smartphones [48]	Rusu et al. [31]
16	u-Learning applications [49]	Rusu et al. [31]
17	Driving simulators [50]	Rusu et al. [31]

Total of studies: 9
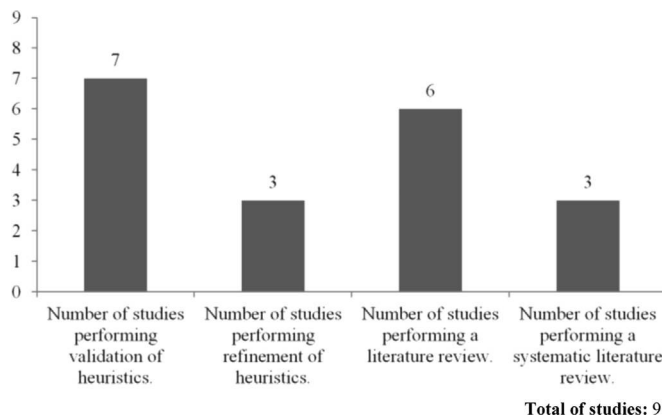
Fig. 4. New set of usability heuristics based on literature reviews.

6.1.5. Establishing a new set of usability heuristics based on mixing processes

6 studies were based on a mixed process to develop usability heuristics. That is, studies used two or more of the following elements to establish new heuristics: (1) existing heuristics; (2) guidelines; (3) a literature review; (4) usability problems; (5) interviews; (6) focus groups; and (7) the context of use of a specific domain.

As shown in Table 11, all 6 studies are based on existing heuristics to develop new heuristics for specific domains [67–72]. Then, the studies complemented the process of heuristic development using others kind of methods or activities.

On the one hand, in [67,68] and [70], the heuristics were established using existing heuristics and guidelines of a specific domain. On the other hand, in [68,69] and [72], the heuristics were

created using existing heuristics and by performing a literature review to collect information about features of a specific domain. Finally, in [70,71] and [72], the heuristics were developed using existing heuristics and usability problems.

Appendix F shows in detail the processes used in the studies.

6.1.6. Establishing a new set of usability heuristics based on guidelines, principles or design recommendations

5 studies were based on existing guidelines, principles or design recommendations – created to design specific domain applications – to establish the new set of usability heuristics [12,73–76].

The typical steps to create heuristics are:

1. Collect information about guidelines, standards or design principles for a specific domain. Then:

1.1. Analyze how the information collected can be used to create heuristics.

1.2. Convert guidelines and design recommendations into usability problems, and then group similar problems into categories.

2. Propose a set of usability heuristics.

3. Validate the effectiveness of heuristics through case studies.

Appendix G provides details on the analyzed studies: authors, domains in which specific heuristics were proposed and how they were defined, specified (template) and validated.

6.1.7. Establishing a new set of usability heuristics based on interviews

3 studies have conducted interviews with users to collect information about the problems they have encountered in using a specific application domain. Then, the information collected is analyzed; the problems are grouped into categories; and finally the set of usability heuristics is proposed [77–79].

For example, Brown [77] conducted a questionnaire asking participants to describe exceptional incidents they encountered when playing a game. The results obtained were divided into categories, and then usability heuristics were created. After that, heuristics were evaluated by a group of game design and usability experts and refined.

A different approach was applied by Katre et al. [79]. An interview was conducted with a physician with the required medical expertise, that is, a person with experience in the specific domain.

Details about the steps and activities performed to develop usability heuristics are provided in Appendix H.

6.1.8. Establishing new set of usability heuristics based on theories

2 studies were based on theories to establish heuristics [80,81]. Both studies reviewed and analyzed theories related to a specific domain. Depending on the information obtained, heuristics were developed. Appendix I shows in detail the activities performed in the two studies.

Table 9
Review, validation and refinement performed in each study analyzed.

N°	Domain	Review performed	Validation performed	Heuristics refinement performed
1	Library web services [56]	Literature review	Yes	No
2	Health Information Systems (HIs) [53]	Systematic literature review	Yes	No
3	Computer games [57]	Literature review	Yes	Yes
4	Web services [58]	Literature review	Yes	Yes
5	Assistive robotic [59]	Literature review	Yes	No
6	Smartphone Mobile Applications [60]	Literature review	Yes	Yes
7	Building Natural User Interfaces Environments [54]	Systematic literature review	No	No
8	Motion-controlled games [61]	Literature review	No	No
9	Gestural interaction [55]	Systematic literature review	Yes	No

Table 10
Steps followed by each study to develop usability heuristics.

Steps to develop the heuristics	Bertini et al. [62]	Pinelle et al. [99]	Sim et al. [63]	Papaloukas et al. [101]	Geerts and Grooff [102]	Singh and Wesson [103]	Yeratziotis et al. [106]	Neto and Pimentel [64]	Carrare et al. [65]
1. Identify usability problems through previous studies	x			x		x			
2. Identify usability problems through usability evaluations		x	x	x	x		x	x	x
3. Select significant usability problems identified	x	x	x	x	x	x	x	x	x
4. Create additional elements to establish heuristics			x			x			x
5. Group usability problems into categories	x	x			x		x	x	
6. Analyze Nielsen's heuristics	x		x					x	x
7. Create the new set of heuristics	x	x	x	x	x	x	x	x	x
8. Validate the heuristics	x	x	x	x		x		x	x

6.2. Recurrent domains for which new usability heuristics were created

After reviewing the 68 articles, we may observe that diverse studies have developed different sets of usability heuristics for the same domains.

Table 12 shows the recurrent domains for which new usability heuristics were created. Out of 68 studies, 11 studies established heuristics for Games. Each set of heuristics was developed for different types of games, such as: (1) Pervasive games [22]; (2) Educational computer games [24,88,89]; (3) Mobile games [27,67,72]; (4) Computer games [24,37,77]; (5) Motion-controlled games [61]; (6) Networked Multiplayer games [99,100]; (7) Video games [101]; and (8) Digital learning games [75].

In addition, 9 studies created heuristics for Mobile. We refer to "mobile" as any system and/or application mobile. Each set of heuristics was developed for different types of mobiles, such as: (1) Mobile games [27,67,72]; (2) Mobile map applications [19]; (3) Mobile interfaces [45]; (4) Smartphone mobile applications [60]; (5) Mobile computing [62]; (6) Mobile devices [64]; and (7) Mobile launchers [76,104].

In addition, 9 studies established heuristics for Systems (that is, software). Each set of heuristics was created for different types of systems, such as: (1) Human-robot interaction systems [23]; (2) Radiology reporting systems [26]; (3) Learning systems [21,65]; (4) Augmented reality systems [36]; (5) Health information systems [53]; (6) ERP systems [103]; (7) Web-based collaboration support systems [71]; and (8) Touch screen systems [79].

Out of 68 studies, 8 studies developed heuristics for Websites. On the one hand, 2 studies presented a set of heuristics only for general websites [15,29,87]; on the other hand, 7 studies presented a set of heuristics for specific types of websites, such as E-government websites [17]; Multi-language websites [18]; Municipal websites [20]; Health social networking websites [51,106]; Transactional websites [46,98]; and Highly interactive websites [66].

In relation to developing a new set of heuristics, of 68 studies, 34 of them (50% of studies) are based on existing heuristics (17 studies) and methodologies (17 studies) to establish heuristics. In this sense, it is interesting to note that:

1. The most recurrent domain used to create heuristics based on existing heuristics is the Websites domain (5 of 17 studies). The other domains that are highlighted are: (1) Games; (2) Systems; (4) Learning; (5) E-learning; and (6) Mobile.
2. The most recurrent domain used to create heuristics based on methodologies is the Applications domain (3 of 17 studies). The other domains that are highlighted are: (1) Websites; (2) Television; (3) Social networks; (4) Interfaces; and (5) Augmented reality.
3. The Website domain is used to create heuristics based on existing heuristics and based on methodologies.
4. The Games domain is used to create heuristics based on: (1) existing heuristics; (2) literature reviews; (3) usability problems; and (4) mixing processes (specifically mobile games).

Based on the above, it is interesting: (1) to know which are the most relevant domains for creating heuristics; and (2) how different studies develop heuristics to evaluate the usability of specific application domains. This is useful to know the areas of software development in which the community is working the most and how different studies try to evaluate usability. Table 13 shows the recurrent domains based on the approach followed to create heuristics and the number of associated studies.

7. Discussion

Section 6 already answered research questions RQ1 and RQ2. We

Table 11
Mixed processes adopted in 6 studies to develop usability heuristics.

Process	Korhonen and Koivisto [67]	Alsumait and Al-Osaimi [68]	Fink et al. [69]	Forsell and Johansson [70]	Karousos et al. [71]	Soomro et al. [72]	Total of studies that used the process
Based on existing heuristics	x	x	x	x	x	x	6
Based on guidelines	x	x		x			3
Based on literature review		x	x			x	3
Based on usability problems				x	x	x	3
Based on context of use	x						1
Based on interviews			x				1
Based on focus group			x				1

Table 12
Recurrent domains for which new usability heuristics were created.

Domain	Number of studies	Studies
Games	11	[22,24,27,57,61,67,72,75,77,88,89,99–101]
Mobile	9	[19,27,45,60,62,64,67,72,76,104]
Systems	9	[21,23,26,36,53,65,71,79,103]
Websites	8	[15,17,18,20,29,46,51,66,87,98,106]
Applications	7	[19,44,47,49,60,63,68]
Interfaces	5	[14,44,45,54,64]
Computers	5	[24,57,63,77,88,89],[78]
Learning	4	[21,27,65,75]

Table 13
Recurrent domains based on the approach followed to create heuristics.

How to develop usability heuristics	Total of studies	Domain	Number of studies	Study references
Based on existing heuristics	17	Websites	5	[15,17,18,20,29,87]
		Games	3	[22,24,27,88,89]
		Systems	3	[21,23,26]
		Learning	2	[21,27]
		E-learning	2	[16,28]
		Mobile	2	[19,27]
Based on methodologies	17	Applications	3	[44,47,49]
		Websites	2	[46,51,98,106]
		Television	2	[40,43,97]
		Social network	2	[42,51,106]
		Interfaces	2	[44,45]
		Augmented reality	2	[36,47]
Based on literature reviews	9	Web services	2	[56,58]
		Games	2	[57,61]
Based on usability problems	9	Mobile	2	[62,64]
		Games	2	[99–101]
		Systems	2	[65,103]
Based on a mixing process	6	Mobile games	2	[67,72]
Based on guidelines or design principles/ recommendations	5	Each study analyzed works in a different domain.		
Based on interviews	3			
Based on theories	2			
Total	68 studies			

will now discuss our main findings and then answer the RQ3 research question. We believe that following a formal process to develop heuristics is very important in order to develop effective and efficient sets of heuristics to evaluate usability. Therefore, it is necessary to discuss and analyze in detail the methodologies that exist, including their strengths and weaknesses.

7.1. How usability heuristics are developed

Nielsen's heuristics make it possible to assess some general usability aspects of any application, such as error prevention; user control and freedom; flexibility and efficiency of use; among others. However, as they are "general heuristics," they ignore critical elements of a specific application. Therefore, it is necessary to develop new specific heuristics to evaluate features or unique aspects of a specific application domain.

The systematic literature review shows that there are various approaches that can be followed to establish usability heuristics. Each approach is different; thus, the formalism and thoroughness of the stages differ among the reviewed studies. We identified eight different approaches to develop usability heuristics: (1) based on existing heuristics; (2) based on methodologies; (3) based on literature reviews; (4) based on usability problems; (5) based on a mixing process; (6) based on guidelines or design principles/ recommendations; (7) based on interviews; and (8) based on theories. This answers the first research question (RQ1: How are usability heuristics developed?).

As reported in the Results section, the most recurrent approaches to establishing usability heuristics are: (1) based on existing usability heuristics, adapted with new heuristics added to evaluate the usability of a specific domain (25% of the reviewed studies); and (2) based on a methodology to create usability heuristics, following some or all of the steps defined in the methodology (25% of the reviewed studies) (see Fig. 5).

On the one hand, based on existing heuristics, new heuristics make it possible to know: (1) which heuristics already exist (to evaluate a specific domain); (2) how heuristics were designed; and (3) what new heuristics have been added to cover the gap that exists, with Nielsen's heuristics to evaluate usability. After this review, it is possible to identify what shortcomings exist in other sets of existing heuristics; therefore:

1. Do not commit the same mistakes when creating new sets of heuristics.
2. Refine and improve sets of existing heuristics, creating a new set, adding or modifying certain elements.
3. Propose entirely new sets of heuristics, since the approach used in other existing sets is not applicable in the specific domain studied.
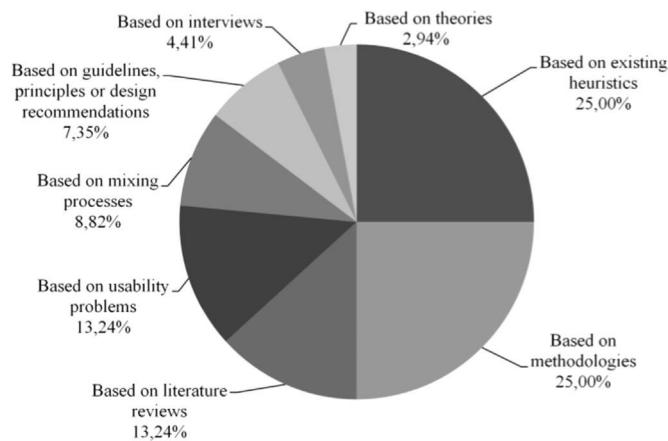
Fig. 5. Percentage of studies associated with each approach to develop heuristics.

Fig. 6. Methodologies used to develop usability heuristics.

However, the process to establish and validate a new set of heuristics should be formal, rigorous and executed by experts in usability and heuristic evaluations, so that the adaptation of existing heuristics will be correct and thorough. Otherwise, the results may be ineffective sets of heuristics (heuristics that are not able to find usability problems) or inefficient sets of heuristics (heuristics that are not able to find more usability problems than existing sets of heuristics, problems encountered that are not critical, or problems that are not specific to the domain evaluated). It is important to highlight that the reviewed studies do not mention the level of experience that is necessary to adapt and create new heuristics.

While the shortcomings of the new set of heuristics proposed can be identified by performing validations (through expert opinion, heuristic evaluation, etc.), the deficiencies found can be numerous, which leads to the process being repeated "n" times to refine the heuristic, until an efficient and effective set is obtained.

On the other hand, out of 73 studies, only 17 studies (25%) used a methodology to establish usability heuristics. We identified 7 methodologies to develop usability heuristics. This answers the second research question (RQ2: Are there methodologies to establish usability heuristics?). Based on the seven (7) methodologies identified in the literature review:

1. Four (4) methodologies were proposed specifically to establish usability heuristics (Rusu et al. [31], Van Greunen et al. [32], Hermawati and Lawson [33], and Lechner et al. [34]). These 4 studies focus mainly on presenting the methodology and its characteristics.
2. Five (5) methodologies are used to develop new heuristics (Rusu et al. [31], Van Greunen et al. [32], Hub and Čapková [35], Franklin et al. [36], and Hevner et al. [37]). There is at least one study that uses these methodologies to develop usability heuristics for a specific application domain.

The methodology proposed by Hevner [37] is not used to design usability heuristics: Abrahao et al. [52] adapted this methodology to create heuristics. Therefore, the literature review shows that there are 4 methodologies proposed to develop usability heuristics for specific domains [31–34], of which only 2 have been used in several studies to establish heuristics [31,32]. The other two methodologies [33,34] have not been used yet to develop heuristics (see Fig. 6).

While only 25% of the studies used a methodology to create new heuristics, this shows the interest in following a formal process to specify heuristics, with clear validation procedures to assess the effectiveness and efficiency of the proposed set of heuristics.

To avoid problems in the specification of heuristics (i.e., ambiguous definitions; very long definitions; or insufficient specification to understand a heuristic), it is essential to follow a standard template to define
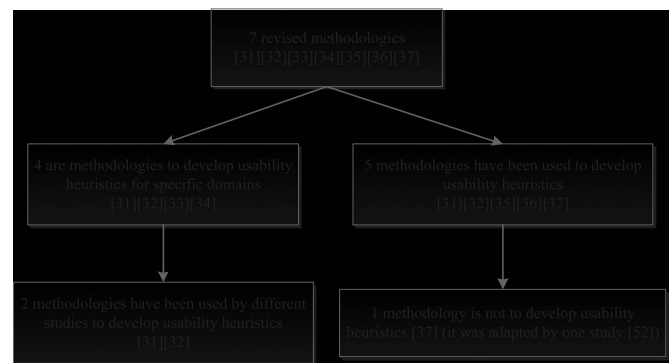
clear and homogeneous heuristics; that is; all heuristics should have the same format and structure definition. Additionally, it is not enough to establish the new set of heuristics for a specific domain; it is also necessary to validate that heuristics find specific domain-related usability issues.

For instance, Van Greunen et al. [32] used two phases to validate the new set of heuristics: First, heuristics are validated by a group of experts in the field, and after refining them; heuristics are used in a real case study. If heuristics do not assess the usability correctly, the steps are repeated to refine the heuristics and obtain an efficient set. Hermawati and Lawson [33] propose a stage that includes the user in the validation process. That is, in addition to performing heuristic evaluations with experts, they also suggest user tests.

7.2. Discussing the methodologies (RQ3)

Seven methodologies were analyzed in order to determine if the stages proposed to develop usability heuristics involve a systematic and formal process. In order to answer the third research question (RQ3: If there are methodologies to establish usability heuristics, do these methodologies propose a formal and systematic process to specify and validate usability heuristics?), each methodology identified in the systematic review is discussed below.

Rusu et al. [31] propose a methodology with six stages. While this methodology facilitates the heuristics' design and specification – as it establishes stages that support the development process and make it possible to formally specify the heuristics given the appropriate validations and refinements – certain deficiencies were detected, such as: (1) descriptive and correlational stages do not adequately explain what activities should be performed; (2) iteration is not explained, nor are the stages to repeat and why; (3) details are not provided regarding when it is appropriate to stop refining the set of heuristics; and so on. Thus, some improvements are needed. These improvements are presented in [110].

Van Greunen et al. [32] propose a three-phase process to create heuristics for specific application domains. They suggest a formal process to create heuristics, clearly explaining each stage and the activities involved. However: (1) how to define or specify the heuristics is not explained (a template is not provided); (2) the authors suggest using a tool to validate the heuristic but do not mention what the tool is or how to use it; (3) validation with real case studies is oriented to websites only; and (4) experience in heuristic evaluations and prior knowledge about usability heuristics are not listed as critical in the selection of users in the validation phase.

Hermawati and Lawson [33] propose a general methodology on how to expand heuristics sets for a specific domain and validate them. The methodology includes two stages. The novelty of this approach is that it includes the users in the development process of the heuristics; however, some activities are unclear and lack information on how to perform certain actions: (1) The stages are explained in paragraphs,

without clearly defining the activities or in what order to perform them; (2) how to define or specify the heuristics is not explained (a template is not provided); (3) how to refine the set of heuristics after validation is not indicated; (4) the validation methods that should be applied are not clearly proposed; and (5) the type of users that should participate in the validation process is not indicated.

Lechner et al. [34] present a methodology to develop a set of domain-specific usability heuristics. The methodology proposes two phases with several activities. In Hermawati and Lawson [33], the authors suggest involving the users in the validation phase. However, no studies using this methodology were found. As in [23] and [33], Lechner et al. do not explain how to define the heuristics. The authors propose a validation based only on users. While the experts work together to create new heuristics, the authors seem to think that a formal validation with experts is unnecessary. The phases are not iterative, and a clear proposal for refining the heuristics is not given. The most problematic element of the methodology is that it does not specify how to evaluate the efficiency and effectiveness of the new heuristics.

The methodology proposed by Hevner et al. [37] is not discussed because it is oriented toward Information Systems. Finally, the methodologies suggested by Hub and Čapková [35] and Franklin et al. [36] are not discussed because they are proposed to create just one specific set of usability heuristics.

The methodologies analyzed are interesting, novel and useful processes to establish usability heuristics. However they lack a formal specification of stages and activities. This proves that the problem described in Section 2, sub-section 4 is real. In conclusion, in response to the third research question (RQ3), there is still no methodology that proposes a formal and systematic process for specifying and validating usability heuristics.

The use of a methodology is crucial to establish usability heuristics and to organize and plan each stage of heuristic development.

7.3. Limitations

The current review has a number of limitations. As with all reviews, it was limited by the search terms used, the databases used and the time period of the papers published. However, the papers discussed in this literature review provided a wide view of (1) the usability heuristics developed; (2) the processes used to establish heuristics; and (3) the methodologies proposed to develop usability heuristics; it is therefore representative of the current state of the art.

In addition, the most relevant databases were taken into consideration, and the most appropriate terms related to the review were searched. The review considers papers published during a period of 10 years (2006 to 2016).

The review excluded studies that do not explain how usability heuristics were specified; the goals were to identify how different authors define new heuristics and which elements they consider necessary to specify.

8. Conclusions

The most notable point about the current review was the diversity of research related to the development of usability heuristics for specific domains. The analysis of different studies provides an overview of several approaches to the creation of usability heuristics and presents the methodologies that were used.

As described in the paper, there are several approaches based on: (1) existing heuristics; (2) methodologies; (3) literature reviews; (4) usability problems; (5) mixing processes; (6) guidelines, principles or design recommendations; (7) interviews; and (8) theories. Of these, the most recurrent approaches to developing heuristics are:

1. Based on existing usability heuristics: Many proposals for usability heuristics are established as an extension or adaptation of Nielsen's heuristics [7]. Nevertheless, it is important to note that many studies also use new sets of heuristics that focus more on the specific domain.
2. Using a methodology to create usability heuristics: This highlights the interest of researchers in having a clear and formal process when creating usability heuristics.

In conclusion, the basic approaches used to create heuristics are based on: (1) existing heuristics; and (2) methodologies. Using a methodology is recommended because clearly defined stages are followed in order to specify, validate and refine heuristics.

After reviewing 73 studies, we emphasize that when creating a new set of heuristics, it is necessary to perform at least the following activities:

1. Determine the specific features of the application in order to evaluate these features based on the new set of heuristics.
2. Identify existing sets of usability heuristics in order to determine how these existing sets can help to define the new heuristics (for instance, which heuristics can be reused and which elements to use to define heuristics).
3. Specify the new set of heuristics following a standard template in order to obtain a set of heuristics that is well defined and easy to understand.
4. Validate the new set of heuristics in order to determine if the heuristics make it possible (1) to find usability problems; and (2) to detect specific usability problems related to the application.

The above activities are necessary to create an effective and efficient set of usability heuristics.

In addition, the analyzed methodologies suggest interesting, novel and useful processes to establish usability heuristics. However, there is no formal specification of the stages or related activities. Moreover, there is currently no clear protocol for heuristics validation.

Nevertheless, it is interesting to note that it seems that the "best" methodologies for developing heuristics are:

1. The methodology proposed by Rusu et al. [31] because it (1) presents clearly defined stages; (2) includes a standard template for specifying heuristics; (3) includes clear validation methods; and (4) can be applied iteratively.
2. The methodology proposed by Van Greunen et al. [32] because it (1) graphically shows each stage, which helps to better understand the methodology; (2) exhaustively explains each of the stages; (3) includes a validation stage; and (4) can be applied iteratively.

Most of the studies do not use a formal process to specify and validate the heuristics proposed. A guide is definitely helpful when developing heuristics since it makes it possible to create effective and well-designed sets of usability heuristics.

In future work, we aim to develop a methodology to establish usability heuristics, with clear steps that follow a formal protocol. We have already published a preliminary proposal of improvements [110] for Rusu et al. [31].

Appendix A. Sets of usability heuristics created by different authors for specific domains

N°	Authors	Year	Domain
1	M. Moraes, M. Silveira [14]	2006	Animated Interface Agents
2	C. Röcker, M. Haar [22]	2006	Pervasive Game Development in Smart Home Environments
3	E. Clarkson, R. C. Arkin [23]	2007	Human-Robot Interaction Systems (HRI)
4	T. Conte, J. Massollar, E. Mendes, G. H. Travassos [15,87]	2007	Websites
5	E.A. Kemp, A. J. Thompson [16]	2008	E-learning
6	H. M. Omar, A. Jaafar [24,88,89]	2010, 2011	Educational Computer Games
7	H. M. Omar, Y. H. M. Yusof, N. M. Sabri [25]	2010	Courseware
8	V. F. M. Salvador, L. de A. Moura Jr. [26]	2010	Radiology Reporting Transcription Systems
9	S. B. Zaibon, N. Shiratuddin [27]	2010	Mobile Game-Based Learning
10	A. Sivaji, A. Abdullah, A. G. Downe [17]	2011	E-government Website
11	M. Andreu-Vall and M. Marcos [18]	2011	Multi-language Websites
12	E. Koulocheri, A. Soumplis, N. Kostaras, M. Xenos [28]	2011	E-learning Environments
13	R. A. Grice, A. G. Bennet, J. W. Fernheimer, C. Geisler, R. Krull, R. A. Lutzky, M. G. J. Rolph [29]	2013	Websites
14	L, Kuparinen, J. Silvennoinen, H. Isomäki [19]	2013	Mobile Map Applications
15	C. Pribeanu [20]	2014	Municipal Websites
16	J. S. Mtebe, M. M. Kissaka [21]	2015	Learning Management System
17	F. O. Andrade, L. N. Nascimiento, G. A. Wood, S. J. Calil [30]	2015	Medical Devices User Manuals
18	M. Hub, V. Čapková [35]	2010	Public Administration Portal
19	C. Rusu, S. Roncagliolo, G. Tapia, D. Hayvar, V. Rusu, D. Gorgan [38,94]	2010, 2011	Grid Computing
20	Rusu, R. Muñoz, S. Roncagliolo, S. Rudloff, V. Rusu, A. Figueroa [39] R. Muñoz, V. Chalegre [95,96]	2011, 2012	Virtual Worlds
21	Alexandros Yeratziotis, Dalenca Pottas, and Darelle Van Greunen [51,106]	2011, 2012	Health Social Networking Websites
22	A. Solano, C. Rusu, C. Collazos, S. Roncagliolo, J. L. Arciniegas, V. Rusu [40] A. Solano, C. Rusu, C. Collazos, J.L. Arciniegas [97]	2011, 2013	Interactive Digital Television
23	J. Díaz, C. Rusu, J. Pow-Sang, S. Roncagliolo [41]	2013	Heuristics with Cultural Aspects
24	R. X. E. de Almeida, S. B. L. Ferreira, D. S. da Silveira, M. Pimentel, R. Goldbach, A. T. Bessa [42]	2013	Social Networks
25	K. R. da H. Rodrigues, C. A. C. Teixeira, V. P de A. Neris [43]	2014	TV Emotion
26	E. V. Neto, F. F.C. Campos [44]	2014	Multimodal Interfaces on Tablets Applications
27	R. Y. Gómez, D C. Caballero, J. L. Sevillano [45]	2014	Mobile Interfaces
28	A. L. Abrahão, A. Cavalcanti, L. L. Pereira, L. G. Roque [52]	2014	Touch and Gesture Interaction
29	F. Franklin, F. Breyer, J. Kelner [36]	2014	Collaborative Augmented Reality Remote Systems (CARRS)
30	F. Paz, F. A. Paz, J. Pow-Sang, L. Collantes [46] F. Paz, F. A. Paz, J. Pow-Sang [98]	2014, 2015	Transactional Websites
31	N. Gale, P. Mirza-Babaei, I. Pedersen [47]	2015	Wearable Augmented Reality Applications
32	R. Inostroza, C. Rusu, S. Roncagliolo, V. Rusu, C. A. Collazos [48]	2016	Smartphones
33	F. Sanz, R. Gálvez, C. Rusu, S. Roncagliolo, V. Rusu, C. A. Collazos, J. P. Cofré, A. Campos, D. Quiñones [49]	2016	U-Learning Applications
34	A. Campos, C. Rusu, S. Roncagliolo, F. Sanz, R. Gálvez, D. Quiñones [50]	2016	Driving Simulators
35	M. R. Aitta, S. Kaleva, T. Kortelainen [56]	2007	Library Web Services
36	C. J. Carvalho, E. M. Borycki, A. Kushniruk [53]	2009	Health Information Systems (HIs)
37	H. Desurvire, C. Wiberg [57]	2009	Computer Games
38	K. Väänänen-Vainio-Mattila, M. Wäljas [58]	2009	Web Services
39	K. M. Tsui, K. Abu-Zahra, R. Casipe, J. M'Sadoques, J. L. Drury [59]	2010	Assistive Robotic
40	G. Joyce, M. Lilley [60]	2014	Smartphone Mobile Applications
41	V. R. M. L. Maike, L. de S. B. Neto, M. C. C. Baranauskas, S. K. Goldenstein [54]	2014	Building Natural User Interfaces Environments
42	M. Hara, S. Ovaska [61]	2014	Motion-controlled Games
43	N. K. Chuan, A. Sivaji, W. F. W. Ahmad [55]	2015	Gestural Interaction
44	E. Bertini, S. Gabrielli and S. Kimani [62]	2006	Mobile Computing
45	D. Pinelle, N. Wong, T. Stach, C. Gutwin [99,100]	2008, 2009	Networked Multiplayer Games

46	G. Sim, J. C. Read, P. Holifield [63]	2008, 2009	Computer Assisted Assessment (CAA) Applications
47	S. Papaloukas, K. Patriarcheas, M. Xenos [101]	2009	Videogames
48	D. Geerts, D. D. Grooff [102]	2009	Social TV
49	A. Singh, J. Wesson [103]	2009	ERP Systems
50	H. Petrie, C. Power [66]	2012	Highly Interactive Websites
51	O. M. Neto, M. de G. Pimentel [64]	2013	Interface of Mobile Devices
52	A. P. G. D. Carrare, C. C. Hernandez, C. Kochi, I. F. Silveira, C. A. Longui [65]	2015	Learning Assessment Systems
53	H. Korhonen, E. M.I. Koivisto [67]	2006	Mobile Games
54	A. Alsumait, A. Al-Osaimi [68]	2010	Child E-learning Applications
55	N. Fink, R. Pak, D. Battisto [69]	2010	Patient Room Bathroom (Building)
56	C. Forsell, J. Johansson [70]	2010	Information Visualization
57	N. Karousos, S. Papaloukas, N. Kostaras, M. Xenos, M. Tzagarakis, N. Karacapilidis [71]	2010	Web-Based Collaboration Support Systems
58	S. Soomro, W. Fatimah, W. Ahmad, S. Sulaiman [72]	2012	Mobile games
59	Y. Afacan, C. Erbug [73]	2008	Universal Building Design
60	C. A. Collazos, C. Rusu, J. L. Arciniegas, S. Roncagliolo [74]	2009	Interactive Television (iTV)
61	P. Jaferian, K. Hawkey, A. Sotirakopoulos, M. Velez-Rojas, K. Beznosov [12]	2011	IT Security Management (ITSM)
62	Y. H. Liao, C. Shen [75]	2012	Digital Learning Games
63	Al-Razgan, Al-Khalifa and Al-Shahrani [76,104]	2012, 2014	Mobile Launchers for Elderly People
64	M. Brown [77]	2008	Computer Games
65	T. Hermann [78]	2009	Computer Supported Collaborative Creativity
66	D. Katre, G. Bhutkar, S. Karmarkar [79]	2010	Touch Screen Ventilator Systems
67	T. Zuk, L. Schlesier, P. Neumann, M. S. Hancock, S. Carpendale [80,105]	2006	Information Visualization
68	E. de Lera, M. Garreta-Domingo [81]	2007	User's Affective Dimension

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Appendix B. Usability heuristics developed based on existing heuristics

N°	Authors	Year	Domain	How heuristics were developed	Template used	Validation method
1	M. Moraes, M. Silveira [14]	2006	Animated Interface Agents	1. Study and extend Nielsen's heuristics. 2. Add to each heuristic specific heuristics that include features related to animated interface agents. 3. Validate the new set of heuristics.	Id, name, description, specific heuristic	Two evaluators evaluate four animated interface agents using the new heuristics.
2	C. Röcker, M. Haar [22]	2006	Pervasive Game Development in Smart Home Environments	1. Study and analyze other existing heuristics: Desurvire et al. heuristics [82] 2. Explore whether existing heuristics can be used by pervasive game developers or if specific design guidelines are required. 3. Evaluate the existing heuristics. 4. Validate the heuristics.	Categories: Id, name, description	Focus group study with 10 participants through scenarios. The results were compared with the heuristics to check whether they could be confirmed or would have to be adapted.
3	E. Clarkson, R. C. Arkin [23]	2007	Human-Robot Interaction Systems (HRI)	1. Create an initial list of HRI heuristics via brainstorming. 2. Synthesizing existing lists of potentially applicable heuristics: Nielsen's heuristics [7,83], Scholtz's guidelines [84], CSCW heuristics [85] and Sheridan's challenges for human-robot	Number, Name (heuristic' authors)	Use the heuristics in an evaluation of an HRI system.

				communication [86]. 3. Specify 8 heuristics. 4. Modify the list based on pilot studies and consultation with other domain experts. 5. Validate the modified list against an existing HRI system. 6. Modify the initial heuristic list based on the results.		
4	T. Conte, J. Massollar, E. Mendes, G. H. Travassos [15,87]	2007	Websites	1. Collect information about web design perspectives. 2. Use the design perspectives collected to interpret Nielsen's heuristics. 3. Group heuristics into categories.	Category name, Heuristic: name, checklist that explains what to evaluate.	Perform a usability inspection to evaluate a real Web application.
5	E.A. Kemp, A. J. Thompson [16]	2008	E-learning	1. Collect information related to E-learning and its features. 2. Adapt and extend Nielsen's heuristics to evaluate invisibility and ubiquity, adding new heuristics to cover specific features. 3. Define 18 usability heuristics and add a checklist to each heuristic.	Heuristic name, description	Evaluate an application using the new set of heuristics.
6	H. M. Omar, A. Jaafar [24,88,89]	2010, 2011	Educational Computer Games	1. Collect information about existing usability heuristics related to games, videogames, mobile games, playability, etc. 2. Create 43 usability heuristics for educational computer games, grouped into 5 categories.	Category name, Id, name of heuristic	Heuristic evaluation with 5 expert evaluators.
7	H. M. Omar, Y. H. M. Yusof, N. M. Sabri [25]	2010	Courseware	1. Collect and analyze information about existing heuristics. 2. Propose initial sets of heuristics. 3. Expert review. Review the set of heuristics through a questionnaire given to the domain expert. 4. Evaluate the heuristics: How many heuristics does each category have? 5. Propose the final set of 33 usability heuristics grouped into 4 categories.	Category name, Id, name of heuristic	N/A
8	V. F. M. Salvador, L. de A. Moura Jr. [26]	2010	Radiology Reporting Transcription Systems	1. Perform a bibliographic review of the themes in use in the project, including: voice user interface (VUI), radiology information systems with VUI and methods of usability evaluation. 2. Identify generic demands for the users interfaces based on voice and the users interface requirements for voice-based system.	Id, name, detailed description, checklist (listed as questions)	Usability evaluation performed by one VUI expert.

				3. Choose heuristics and propose 6 new heuristics and checklists according to peculiarities of VUI and voice-based systems in Health Care. 4. Apply the proposed heuristics to an automatic transcription system for radiology reports and obtain results.		
9	S. B. Zaibon, N. Shiratuddin [27]	2010	Mobile Game-Based Learning	1. Collect information about game usability, mobile game, game play, learning content and existing heuristics. 2. Create usability heuristics based on Korhonen and Koivisto's heuristics [67] and adding a learning content component. 27 heuristics were created and grouped into 4 categories.	Heuristic components, Id, name	Evaluation with end-users. Users evaluate an application using the heuristics proposed.
10	A. Sivaji, A. Abdullah, A. G. Downe [17]	2011	E-government Website	1. Collect information about heuristic evaluation and Nielsen's heuristics. 2. Define 12 usability heuristics based on modified Nielsen's heuristics. New heuristics are added to evaluate new website features.	Name, description	Heuristic evaluation applying the new set of heuristics. Usability testing.
11	M. Andreu-Vall and M. Marcos [18]	2011	Multi-language Websites	1. Collect information about existing heuristics (Nielsen's heuristics), aspects related to localization and usability standards, guidelines from the World Wide Web Consortium (W3C) and specific features of the application 2. Develop 24 usability heuristics grouped into 5 categories.	Title, description, example (as code html or explanatory images), impact of the lack of compliance (1, 2, 3 scale)	N/A
12	E. Koulocheri, A. Soumplis, N. Kostaras, M. Xenos [28]	2011	E-learning Environments	1. Review several existing heuristics (Nielsen's [7], Arito's [90] and Reeves's [91] heuristics). 2. Modify existing heuristics and create 5 new specific heuristics for the evaluation of an e-learning environment. Total heuristics: 15. 3. Validate the new set of heuristics through heuristic evaluation.	Id, name, description	Heuristic evaluation with 4 evaluators.
13	R. A. Grice, A. G. Bennet, J. W. Fernheimer, C. Geisler, R. Krull, R. A. Lutzky, M. G. J. Rolph [29]	2013	Websites	1. Perform a literature review. 2. Check existing heuristics (Nielsen's heuristics [7]), Hargis et al. [92]. 3. Expand existing heuristics via an iterative process until they more fully describe the usability and	Heuristic name and sub-items related to each heuristic, metrics associated (product and survey metric)	Use heuristics in case studies.

				user experience in the social-media environment. 4. Define (1) a set of heuristics that can be used to guide design or assess usability and UX; and (2) metrics that can be used to examine how optimally a design meets the criteria outlined in the heuristics.		
14	L, Kuparinen, J. Silvennoinen, H. Isomäki [19]	2013	Mobile Map Applications	1. Explore the generic heuristics (Nielsen) and point out its limitations in evaluating the usability of the application in the study. 2. Become familiar with existing domain-specific heuristic sets and explore which methods were used by these authors to develop these heuristics, e.g., [93]. 3. Formulate the new heuristics. 4. Test the applicability of the initial usability heuristics for application in the study.	Id, title, description, justification	– Heuristic evaluation. Two groups participated. One group used the Nielsen' heuristic, and another used a new set of heuristics. – They asked the evaluators to rate the applicability of the heuristics for evaluating mobile map applications and the intelligibility of each of the heuristics.
15	C. Pribeanu [20]	2014	Municipal Websites	1. Review existing heuristics that have been developed to evaluate websites and ergonomic criteria. 2. Create 25 usability heuristics integrating Nielsen's heuristics with ergonomic criteria. The heuristics are grouped into 6 ergonomic criteria. 3. Validate the set of heuristics. 4. Refine the set of heuristics with the results obtained in the previous stage.	Category, Number, name	N/A
16	J. S. Mtebe, M. M. Kissaka [21]	2015	Learning Management System	1. Review existing heuristics. 2. Adapt and refine Nielsen's heuristics to category "interface usability" and adapt other sets of heuristics for each heuristic sub-criteria. 3. Extract heuristics from previous studies to develop heuristic for category "didactic effectiveness". 4. Validate the set of heuristics through experiments.	Number, name, description, sub-criteria's	Heuristic evaluation with 5 experts. The experts evaluate two selected systems.
17	F. O. Andrade, L. N. Nascimiento, G. A. Wood, S. J. Calil [30]	2015	Medical Devices User Manuals	1. Collect information about existing heuristics and guides for developing medical devices user manuals. 2. Define new set of 14 heuristics.	Name, definition	Associate usability problems to the new set of heuristics.

Appendix C. Usability heuristics developed based on methodologies

Nº	Authors	Year	Domain	How heuristics were developed	Template used	Validation method
1	M. Hub, V. Čapková [35]	2010	Public Administration Portal	1. Identify basic set of heuristics. Collect information about existing heuristics. 2. Specify the requirements on resources. Identify the necessary working roles for heuristics creation (experts, project manager, teams, etc.) 3. Analyze the environment. Become familiar with the concrete type of user interface and its specificity. 4. Prepare the heuristics creation. Choose a project manager, a usability expert, and project team, and assign a workplace and equipment. 5. Create the set of usability heuristics. Select, categorize, add and modify the basic set of heuristics collected in step 1. 6. Evaluate the set of heuristics. The result of this phase is a final set of heuristics. 7. Propose the final set of usability heuristics.	No template – 7 heuristic categories – Number of heuristics: 92	Heuristic evaluation.
2	C. Rusu, S. Roncagliolo, G. Tapia, D. Hayvar, V. Rusu, D. Gorgan [38,94]	2010, 2011	Grid Computing	Apply a methodology proposed by Rusu et al. [31]. The methodology includes 6 stages. Stages 1 to 6 may be applied iteratively. 1. Exploratory stage: to explore the specific applications that require new heuristics. 2. Descriptive stage: to re-examine the very meaning of usability and its features. 3. Correlational stage: to identify the features that the usability heuristics for specific applications should have. 4. Explicative stage: to specify new heuristics. 5. Validation stage: to evaluate the set of heuristics defined at STEP 4. 6. Refinement stage: to refine the set of heuristics defined at STEP 4.	Id, name, definition, explanation, examples, benefits, problems. – Number of heuristics: 12	– Two heuristic evaluations with two groups of 3–4 evaluators each: One group (called control group) used Nielsen's heuristics and another group (called the experimental group) used the new set of heuristics. Both groups evaluate the same application. – Usability test, with 5 users.
3	Rusu, R. Muñoz, S. Roncagliolo, S. Rudloff, V. Rusu, A. Figueroa [39] R. Muñoz, V. Chalegre [95,96]	2011, 2012	Virtual Worlds		Id, name, definition, explanation, examples, benefits, problems. 1. Number of heuristics: 16	Heuristic evaluations with two groups of 3 evaluators each: one group (called the control group) used Nielsen's heuristics and another group (called the experimental group) used the new set of heuristics. Both groups evaluate the same application.
4	A.Yeratziotis, D. Pottas, and D. Van Greunen [51,106]	2011, 2012	Health Social Networking Websites	Applying a methodology proposed by Van Greunen et al. [32]. 1. Review the literature in the fields of usability, usable	Name, description	Evaluate applications related to health.

security, security, and privacy to identify relevant secondary data source.
2. Define high-level heuristics according to themes identified.
3. Tailor existing heuristics to fit the specific application domain.
4. Group checklist items based on high-level heuristic names.
5. Review grouping of checklist items.
6. Validate the set of heuristics. For that, identify and select experts. Apply a validation tool to validate the high-level heuristics and analyze the results.
7. Iterate, refine and redesign the heuristics.
8. Apply the set of heuristics in a case study.

5	A. Solano, C. Rusu, C. Collazos, S. Roncagliolo, J. L. Arciniegas, V. Rusu [40] A. Solano, C. Rusu, C. Collazos, J.L. Arciniegas [97]	2011, 2013	Interactive Digital Television	Applying a methodology proposed by Rusu et al. [31]. The methodology includes 6 stages. Stages 1 to 6 may be applied iteratively. 1. Exploratory stage: to explore the specific applications that requires new heuristics. 2. Descriptive stage: to re-examine the very meaning of usability and its features. 3. Correlational stage: to identify the features that the usability heuristics for specific applications should have. 4. Explicative stage: to specify new heuristics. 5. Validation stage: to evaluate the set of heuristics defined at STEP 4. Refinement stage: to refine the set of heuristics defined at STEP 4.	Id, name, definition, explanation, examples, benefits, problems, checklist. 1. Number of heuristics: 14, grouped in three categories.	Two heuristic evaluations with two groups: one group (called the control group) used Nielsen's heuristics and another group (called the experimental group) used the new set of heuristics. Both groups evaluate the same application.
6	J. Díaz, C. Rusu, J. Pow-Sang, S. Roncagliolo [41]	2013	Heuristics with Cultural Aspects		ID, name, definition, associated cultural dimension, explanation, emphasis, example, benefits 1. Number of heuristics: 13	1. Two heuristic evaluations with two groups of 3 evaluators each: One group (called the control group) used Nielsen's heuristics, and another group (called the experimental group) used the new set of heuristics. Both groups evaluate the same application. 2. Validation through expert researchers in usability.
7	R. X. E. de Almeida, S. B. L. Ferreira, D. S. da Silveira, M. Pimentel, R. Goldbach, A. T. Bessa [42]	2013	Social Networks	Applying a methodology proposed by Rusu et al. [31]. They used the first four stages (from 6 proposed in the methodology). 1. Exploratory stage: to explore the specific applications that requires new heuristics. 2. Descriptive stage: to re-examine the very meaning of usability and its features. 3. Correlational stage: to identify the features that the usability heuristics for specific applications should	Name, description 1. Number of heuristics: 7	N/A

			have.
			4. Explicative stage: to specify new heuristics.

| 8 | K. R. da H. Rodrigues, C. A. C. Teixeira, V. P de A. Neris [43] | 2014 | TV Emotion | Applying a methodology proposed by Rusu et al. [31]. The methodology includes 6 stages. Stages 1 to 6 may be applied iteratively.
 1. Exploratory stage: to collect bibliographic material related to the main topics of the research: specific applications, their characteristics, general and/or related heuristics (if they exist).
 2. Descriptive stage: to highlight the key features of the previously collected information, to formalize the main concepts associated with the research.
 3. Correlational stage: to compare similar characteristics between the proposed heuristics and the heuristics outlined in the literature for specific applications. This stage is based on traditional heuristics and an analysis of case studies.
 4. Explicative stage: to formally specify the set of proposed heuristics using a template.
 5. Validation stage: to compare the new heuristics with traditional heuristics by conducting experiments involving heuristic evaluations carried out with selected case studies, and supplemented with user tests.
 6. Refinement stage: based on feedback from the validation stage. | Id, name, description, experience
 1. Number of heuristics: 23 | 1. Heuristic evaluation with 5 evaluators. One group evaluates an application using the new set of heuristics, and another group evaluates the same application using the "Ten emotion heuristics" [81].
 2. Scenarios. |
| 9 | E. V. Neto, F. F.C. Campos [44] | 2014 | Multimodal Interfaces on Tablets Applications | Applying a methodology proposed by Rusu et al. [31]. They used five stages (from 6 proposed in the methodology).
 1. Step 1: A heuristics review was done from the literature.
 2. Step 2: Characteristics of multi-touch and speech interaction were surveyed.
 3. Step 3: Guidelines for developers from iOS, Android and Microsoft Surface documentation were examined.
 4. Step 4: A cross between the information collected was performed, and the new set | Id of Nielsen's heuristics, Multi-touch heuristics, speech characteristics | Heuristic evaluation to compare the new set of heuristics and Nielsen's heuristics.
 12 designers divided into 3 groups performed heuristic evaluations on three tablet applications. |

			of heuristics was compiled. 5. Step 5: Validate the heuristics with expert evaluators, comparing the new set of heuristics with traditional heuristics.		
10	R. Yáñez Gómez, D C. Caballero, J. L. Sevillano [45]	2014	Mobile Interfaces	Applying a methodology proposed by Rusu et al. [31], but with slight modifications. 1. A clear definition of the problem scope is necessary as a first step to define and classify the special characteristics of mobile interaction. 2. Rearrange existing and well-known heuristics into a new compilation. They reuse heuristic guidelines from the literature and adapt them to the new mobile paradigm. 3. Develop a compilation of different proposed sub-heuristics. "Heuristic" for these authors refers to a global usability issue that must be evaluated or taken into account when designing. In contrast, the term "sub-heuristic" refers to specific guideline items. 4. Enrich the list with mobile-specific sub-heuristics. The sub-heuristics are gleaned from mobile usability studies and best practices proposed in the literature. 5. Homogenize the redaction and format of sub-heuristics in order to make it useful for non-experts. 6. Conduct an evaluation of the usefulness of the tool as an aid in designing for mobile.	Id, heuristic, sub-heuristics 1. Number of heuristics: 13	N/A
11	A. L. Abrahão, A. Cavalcanti, L. L. Pereira, L. G. Roque [52]	2014	Touch and Gesture Interaction	Applying a methodology proposed by Hevner [37], the Design Research methodology, with 5 stages. 1. Problem identification and awareness (awareness of problem). 2. Proposal of solutions to the problem (suggestion). In this case, define the set of 6 usability heuristics. 3. Prototyping (development of artifacts). Prototype to validate the heuristics. 4. Evaluation. 5. Statement of learning, which can be characterized as the phase of knowledge production.	Before each heuristic, the most important references are presented. Name, references, Id, description.	1. Prototyping. Two prototypes for applicability analysis and calibration of heuristics. 2. Design walkthrough, with 6 users.
12	F. Franklin, F. Breyer, J. Kelner [36]	2014	Collaborative Augmented	Applying a methodology created by authors to develop	Id, name, description	Focus group. Heuristic evaluation with 5

			Reality Remote Systems (CARRS)	the new set of heuristics. 1. Review: Review not only lists of heuristics but also guidelines and/or design principles that can be used as a basis for adaptation and the proposed new list of usability heuristics. 2. Elimination. Check the lists of heuristics selected in the previous stage and choose which heuristics can be used to evaluate CARRS and eliminate those that have a low contribution. 3. Group based on similarity. Select and group heuristics with similar concepts. 4. Fuse concepts based on similarity. Merging similar concepts. In each merging, similar concepts are adapted in a heuristic and some attributes are added. 5 heuristics were proposed based on heuristics selected in the previous stage. 5. Grouping and Adaptation. Group and heuristics that were not used in the stage "Group similar". Each group created is called "base" and are the basis for adapting a heuristic. 6. Preliminary resettlement and adaptation. Present a preliminary proposal of heuristics and checklists to evaluate the usability of CAARS. 7. Focus Group. A focus group is conducted to obtain feedback from specialists. 5 specialists analyze the set of heuristics. 8. Final Result: Refine the set of heuristics from recommendations given by the specialists. 9 heuristics are proposed to evaluate CAARS. 9. Validate the set of heuristics.		experts, using the new set of heuristics.
13	F. Paz, F. A. Paz, J. Pow-Sang, L. Collantes [46] F. Paz, F. A. Paz, J. Pow-Sang [98]	2014, 2015	Transactional Websites	Applying a methodology proposed by Rusu et al. [31]. The methodology includes 6 stages. Stages 1 to 6 may be applied iteratively. 1. Exploratory stage: to explore the specific applications that require new heuristics. 2. Descriptive stage: to re-examine the very meaning of usability and its features.	Id, name, definition 1. Number of heuristics: 15	1. Two heuristic evaluations with two groups: One group (called the control group) used Nielsen's heuristics, and another group (called the experimental group) used the new set of heuristics. 2. Method evaluation model (MEM). They focused on the perception/ intention-based variables of the MEM.

				3. Correlational stage: to identify the features that the usability heuristics for specific applications should have. 4. Explicative stage: to specify new heuristics. 5. Validation stage: to evaluate the set of heuristics defined at STEP 4. 6. Refinement stage: to refine the set of heuristics defined at STEP 4.		
14	N. Gale, P. Mirza-Babaei, I. Pedersen [47]	2015	Wearable Augmented Reality Applications	Applying a methodology proposed by Rusu et al. [31]. They used four stages (from 6 proposed in the methodology). 1. Exploratory stage: to explore the specific applications that require new heuristics. 2. Descriptive stage: to re-examine the very meaning of usability and its features. 3. Correlational stage: to identify the features that the usability heuristics for specific applications should have. Nielsen's Heuristic [4] was the initial starting point, but then they found most of Korhonen and Koivisto's heuristics [64]. 4. Explicative stage: to specify new heuristics.	Id, definition 1. Number of heuristics: 26	N/A (They are planning a validation through heuristic evaluation for the future)
15	R. Inostroza, C. Rusu, S. Roncagliolo, V. Rusu, C. A. Collazos [48]	2016	Smartphones	Applying a methodology proposed by Rusu et al. [31]. The methodology includes 6 stages. Stages 1 to 6 may be applied iteratively. 7. Exploratory stage: to explore the specific applications that require new heuristics. 8. Descriptive stage: to re-examine the very meaning of usability and its features. 9. Correlational stage: to identify the features that the usability heuristics for specific applications should have. 10. Explicative stage: to specify new heuristics. 11. Validation stage: to evaluate the set of heuristics defined at STEP 4. 12. Refinement stage: to refine the set of heuristics defined at STEP 4.	Id, name, definition, explanation, examples, benefits, problems. 1. Number of heuristics: 12	1. Three heuristic evaluations (HE) with two groups: One group (called the control group) used Nielsen's heuristics, and another group (called the experimental group) used the new set of heuristics. Both groups evaluate the same application in each HE, but different applications were evaluated in each HE. 2. Validation by expert researchers in usability and HE. 3. Validation through an inquiry test.
16	F. Sanz, R. Gálvez, C. Rusu, S. Roncagliolo, V. Rusu, C. A. Collazos, J.	2016	U-Learning Applications	Applying a methodology proposed by Rusu et al. [31]. The methodology includes 6	Id, name, definition 1. Number of heuristics: 16	1. Two heuristic evaluations with two groups: One group (called the control

				stages. Stages 1 to 6 may be applied iteratively.		group) used Nielsen's heuristics, and another group (called the experimental group) used the new set of heuristics. Both groups evaluate the same applications, but two different applications were evaluated in each heuristic evaluation.
	P. Cofré, A. Campos, D. Quiñones [49]			1. Exploratory stage: to explore the specific applications that require new heuristics. 2. Descriptive stage: to re-examine the very meaning of usability and its features. 3. Correlational stage: to identify the features that the usability heuristics for specific applications should have.		
17	A. Campos, C. Rusu, S. Roncagliolo, F. Sanz, R. Gálvez, D. Quiñones [50]	2016	Driving Simulators	4. Explicative stage: to specify new heuristics. 5. Validation stage: to evaluate the set of heuristics defined at STEP 4. 6. Refinement stage: to refine the set of heuristics defined at STEP 4.	Id, name, definition 1. Number of heuristics: 16	2. Expert opinion providing feedback about the set of heuristics. Heuristic evaluation. Three experts evaluated an application using HS heuristics (experimental group); The other three experts evaluated the same application using Nielsen's heuristics (control group).

Appendix D. Usability heuristics developed based on literature reviews

N°	Authors	Year	Domain	How heuristics were developed	Template used	Validation method
1	M. R. Aitta, S. Kaleva, T. Kortelainen [56]	2007	Library Web Services	1. Collect information related to usability, usability heuristics and library web services. 2. Define new set of 9 heuristic based on Nielsen's heuristics. 3. Validate the heuristics through heuristic evaluation and usability test.	Number, definition and/or description, list details.	Two heuristic evaluations using the new set of heuristics with 4 evaluators and a usability test with 8 users.
2	C. J. Carvalho, E. M. Borycki, A. Kushniruk [53]	2009	Health Information Systems (HIs)	1. Perform a systematic review to identify published research that outlines any potential harm arising from the use of HISs. 2. Conduct a round-table discussion between three health informatics experts during which the findings from phase one are reviewed. 3. Select 38 heuristics to evaluate HIS with the information collected. 4. Validate the set of heuristics in real conditions. 5. Select a sub-set of heuristics to evaluate HIS features grouped into categories.	Category, Id, name	Through an ecologically valid scenario. An analyst using heuristics to conduct a heuristic evaluation of a demonstration version of a system.
3	H. Desurvire, C. Wiberg [57]	2009	Computer Games	1. Perform a literature review about games development, guidelines and existing heuristics. 2. Develop a set of heuristics for playability. 3. Validate the set of heuristics through different case studies. 4. Refine the set of heuristics. 5. Specify the final set of 19 general heuristics grouped into 3 categories. A total of 59 specific heuristics.	Category, Id, general heuristic, specific heuristics for general heuristic	Playability sessions with thinking aloud questionnaire techniques. Each session was organized as a one-on-one evaluation session, in an environment similar to the one where they would actually play the game.

4	K. Väänänen-Vainio-Mattila, M. Wäljas [58]	2009	Web Services	1. Perform a literature review about web services and on informal analysis of existing services. 2. Create a set of 7 service UX heuristics. 3. Validate the set of heuristics through three applications (services). 4. Refine and add new UX heuristics using the results obtained in the evaluations of the previous stage. 5. Specify the final 9 service UX heuristics.	Id, name, description	Evaluate three applications (services) using the new set of heuristics. Three UX experts evaluate each service.
5	K. M. Tsui, K. Abu-Zahra, R. Casipe, J. M'Sadoques, J. L. Drury [59]	2010	Assistive Robotic	1. Examine the literature for accessibility in human-computer interaction, assistive robotics and social robotics. 2. Examine how each of Nielsen's heuristics relates to the Model-Human Processor. 3. Create a set of 9 usability heuristics adapting Nielsen's heuristics and creating new heuristics.	Name, enumerating details, source (when applicable)	Two heuristic evaluation with four evaluators. Two evaluators used the set of heuristics for assistive robotics heuristics, and the remaining two used Nielsen's heuristics.
6	G. Joyce, M. Lilley [60]	2014	Smartphone Mobile Applications	1. Review the literature to understand how a heuristic evaluation and heuristics may be applied to the mobile panorama. 2. Devise 11 usability heuristics using Nielsen's heuristics [7] as a point of reference. 3. Review the set of heuristics by HCI experts and researchers. 4. Refine the set of heuristics proposed and add new heuristics. 5. Specify the final set of 13 heuristics.	Id, name, description	Online survey with HCI experts and researchers.
7	V. R. M. L. Maike, L. de S. B. Neto, M. C. C. Baranauskas, S. K. Goldenstein [54]	2014	Building Natural User Interfaces Environments	1. Perform a systematic literature review for the purpose of answering the research questions and identify related usability heuristics. 2. Compile 23 usability heuristics related to user interface environments.	Category, Id, name, description	N/A
8	M. Hara, S. Ovaska [61]	2014	Motion-controlled Games	1. Select and analyze a number of game reviews published in many different websites. 2. Detail the information obtained in the reviews. 3. Group problems collected into concept categories form the basis of the emerging heuristics. 4. Analyze the problem categories. 5. Define a set of 13 usability heuristics for the design of motion-controlled games.	Name, explanation, Id	N/A
9	N. K. Chuan, A. Sivaji, W. F. W. Ahmad [55]	2015	Gestural Interaction	1. Perform a systematic literature review to study previous works and adopt a suitable gesture definition and framework. 2. Review and gather gesture-related usability heuristics. 3. Combine the gathered heuristics. Authors use a simple phenomenon or phase-based	A table with: 1. Rows: Study title 2. Columns: Phases (before, during, after and prolonged using)	Heuristic evaluation with 5 usability Practitioners that use the new set of heuristics.

classification method to group and combine these heuristics. The 4 gesture heuristics are put into four phases: "Before using", "During using", "After using", and "Prolonged using".

4. Validate the heuristics.

Appendix E. Usability heuristics developed based on usability problems

N°	Authors	Year	Domain	How heuristics were developed	Template used	Validation method
1	E. Bertini, S. Gabrielli and S. Kimani [62]	2006	Mobile Computing	1. Collect studies that document usability problems related to mobile computing. 2. Three expert researchers consolidate and refine the results. 3. Each researcher groups usability problems into categories separately. 4. Researchers consolidate and refine categories. 5. Each researcher worked individually to assess which of Nielsen's heuristics are considered irrelevant and relevant for mobile settings (with some revision or modification if necessary) and which additional heuristics needed to be included. 6. Researchers compared their table of heuristics proposed to produce a new consolidated table. 7. Refine heuristics involving expert researchers in the field of mobile computing and usability, to give feedback on the adequacy of the heuristics proposed. 8. Researchers discussed and compared the comments received and present the final set of 8 heuristics.	Heuristic Id, name, description	Perform a heuristic evaluation of two mobile applications with 8 experts, to compare the new set of mobile heuristics versus Nielsen's heuristics.
2	D. Pinelle, N. Wong, T. Stach, C. Gutwin [99,100]	2008, 2009	Networked Multiplayer Games	1. Identify real-world usability problems that provide breadth and depth coverage of the game design space. 2. Develop a set of categories that group similar usability problems. 3. Create heuristics that are the inverse of the problem categories and that describe how common usability problems can be avoided. 4. Validate the heuristics through case studies.	Id, name, description	Perform a heuristic evaluation.
3	G. Sim, J. C. Read, P. Holifield [63]	2008, 2009	Computer Assisted Assessment (CAA) Applications	1. Usability problems related to CAA applications gathered through a series of evaluations. 2. A filtering process is applied to the list of usability problems to extract only the frequent or most severe problems. 3. The list is used for the synthesis of CAA heuristics.	Task, problem, consequence, heuristic. Heuristic, description.	N/A

					4. Tasks are used as the initial starting point for the development of the heuristics along with an analysis of Nielsen's heuristics [7].		
					5. Each of the problems is mapped to a task and groupings are formed that enable the synthesis of 11 heuristics.		
4	S. Papaloukas, K. Patriarcheas, M. Xenos [101]	2009	Videogames		1. Analyze, identify and classify usability problems or fun problems found in game reviews and studies.	Id, name, description	Heuristic evaluation. Evaluate a user interface of a game. The users were recorded while playing the game (user logging, combined with thinking aloud).
					2. Observe how players interact with a game, recording the usability problems that they may encounter.		
					3. Categorize similar usability problems which occurred in previous stages.		
					4. Create 10 usability heuristics that describe how usability problems can be resolved; the rules that a game must comply to.		
					5. Test new sets of heuristics by an integrated experimental procedure.		
5	D. Geerts, D. D. Grooff [102]	2009	Social TV		1. Evaluate an application by representative users, through user tests, questionnaires and interviews.	Number, name, explanation	N/A
					2. Distill the issues related to social interaction obtained in the experiments.		
					3. Classify similar issues into the same categories.		
					4. Translate usability problems into 12 sociability guidelines (heuristics).		
6	A. Singh, J. Wesson [103]	2009	ERP Systems		1. Review the literature to collect and find usability problems related to ERP systems.	Criteria, heuristic name	Heuristic evaluation with 3 usability experts, through scenarios.
					2. Establish a common set of 5 criteria for evaluating the usability of an ERP system.		
					3. Combine the criteria established and create a set of heuristics.		
					4. Verify the proposed usability heuristics in terms of their ability to identify the potential usability issues with an ERP system.		
7	H. Petrie, C. Power [106]	2012	Highly Interactive Websites		1. Three experts evaluate 3 websites using think-aloud protocols and 6 websites to identify usability problems.	Category, Id, name, description, rationale, frequency	N/A
					2. Unify a list of usability problems from all the methods. A strict procedure is followed for matching problems from different methods.		
					3. Categorize the usability problems.		
					4. Analyze and group the initial set of categories into more abstract categories.		
					5. Propose a new set of 21 heuristics for developing and evaluating		

| 8 | O. M. Neto, M. de G. Pimentel [64] | 2013 | Interface of Mobile Devices | 1. Analyze four android-based applications in order to identify usability problems and verify whether each of these problems could easily be associated to at least one of Nielsen's heuristics [7].
2. Categorize the usability problems. 19 categories were created.
3. Associate each category of problems to each Nielsen heuristic (when possible).
4. Compile a set of 11 heuristics for mobile device interfaces. | Id, name, description | Heuristic evaluation, with 10 usability specialists with knowledge of the Android operating system and experience with touch screen devices. Five evaluators used Nielsen's heuristics, whereas another five evaluators used heuristics for mobile devices. |
| 9 | A. P. G. D. Carrare, C. C. Hernandez, C. Kochi, I. F. Silveira, C. A. Longui [65] | 2015 | Learning Assessment Systems | 1. Conduct research about learning assessment.
2. Select two applications to analyze the resources available for the learning assessment based on clinical cases.
3. Identify usability problems and positive/negative characteristics.
4. Associate at least one Nielsen's heuristic to each positive or negative characteristic.
5. Consolidate the results, highlighting Nielsen heuristics that are unfulfilled.
6. Analyze the Nielsen heuristics considering the results. Check if the problems and positive/negative characteristics can be represented clearly or whether a more specific definition is needed.
7. Formalize the definition of the 22 heuristics considering the results.
8. Validate the new set of heuristics. | Id, name, description | Heuristic evaluation with 7 experts. |

Appendix F. Usability heuristics developed based on a mixing process

N°	Authors	Year	Domain	Process followed	How heuristics were developed	Template used	Validation method
1	H. Korhonen, E. M.I. Koivisto [67]	2006	Mobile Games	– Based on mobile games context of use – Based on existing heuristics – Based on guidelines	1. Analyze the mobile games context of use and their specific features. 2. Review Nielsen's heuristics and game design guidelines. 3. Specify 11 new heuristics. 4. Validate heuristics with heuristic evaluation. 5. Refine and add the new heuristics. 6. Specify 29 heuristics categorized into three groups. 7. Validate heuristics again.	Id, category name, heuristic name	Evaluate mobile games using the first new set of heuristics with 4 evaluators. Evaluate five mobile games using the second set of heuristics.

2	A. Alsumait, A. Al-Osaimi [68]	2010	Child E-Learning Applications	– Based on literature review. – Based on guidelines. – Based on existing heuristics.	1. Review the literature about existing heuristics, e-learning applications, guidelines, checklists, etc. 2. Define three categories of heuristics based on Nielsen's heuristics [7], children's preferences and abilities, and learner-centered design. Total heuristics: 20. 3. Validate the set of heuristics through case studies.	Category, Id, name of heuristic, explanation	Heuristic evaluation and usability testing.
3	N. Fink, R. Pak, D. Battisto [69]	2010	Patient Room Bathroom (Building)	– Based on literature review – Based on interviews – Based on focus groups – Based on existing heuristics (Nielsen's heuristics)	1. Collect information about nurses' opinions on various bathroom designs. 2. Review the literature of existing heuristics, safety checklists, and reported hospital bathroom problems. 3. Conduct interviews to gather nurses' perceptions of current patient room bathrooms and any problems they had experienced. 4. Conduct focus groups to gather nurses' feedback on a prototype patient room bathroom. 5. Identify the problems obtained from the literature, interviews and focus groups, and categorize them. 6. Formulate the set of 10 heuristics.	Number, name, description. For each heuristic: an item to mark the compliance of heuristic (yes, no, N/A) and its severity (low, medium, high)	N/A
4	C. Forsell, J. Johansson [70]	2010	Information Visualization	– Based on existing heuristics – Based on guidelines – Based on usability problems	1. Identify existing heuristics. 2. Collect information about guidelines for information visualization. 3. Refine a large number of heuristics into a new set of 10 heuristics based on six of the sets described and collected. 4. Perform a heuristic evaluation to find usability problems and associate it with the heuristics defined.	Id (capital letter and number), name, description	N/A

| 5 | N. Karousos, S. Papaloukas, N. Kostaras, M. Xenos, M. Tzagarakis, N. Karacapilidis [71] | 2010 | Web-Based CollaborationSupport Systems | – Based on usability problems
 – Based on existing heuristics (Nielsen's heuristics) | 1. Analyze existing scientific studies, identification and classification of usability problems for web-based collaboration systems, and extraction of a set of specifications.
 2. Observe users interacting with the system, while the evaluation expert records the usability problems they may encounter. At this stage, known heuristics are extended to more specific ones, according to the particular requirements.
 3. Create 10 usability heuristics that describe how usability problems can be resolved.
 4. Use and validate heuristics by an integrated experimental procedure. | Id, heuristic name, summary | Heuristic evaluation by usability experts, during which most usability problems of the software are detected. Heuristics verification is achieved by using an observation and logging combined with the thinking-aloud technique and questionnaires adapted upon the heuristics. |
| 6 | S. Soomro, W. Fatimah, W. Ahmad, S. Sulaiman [72] | 2012 | Mobile Games | – Based on literature review
 – Based on playability problems
 – Based on existing heuristics | 1. Perform a literature review about existing heuristics.
 2. Identify playability problems in mobile games from literature review and those that were not covered by the heuristics proposed by Korhonen & Koivisto [67].
 3. Develop problem categories to group the problems identified.
 4. Conduct questionnaire and interviews to collect data.
 5. Analyze the collected data.
 6. Propose a set of 10 heuristics for mobile games. | Category name, Id, heuristic name, description | N/A |

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Appendix G. Usability heuristics developed based on guidelines or design principles/recommendations

Nº	Authors	Year	Domain	How heuristics were developed	Template used	Validation method
1	Y. Afacan, C. Erbug [73]	2008	Universal Building Design	1. Collect information about guidelines, accessibility standards and design principles. 2. Define 7 usability heuristics based on design considerations of universal design principles. 3. Validate heuristics through case studies.	Id, name, definition, design consideration	Through three scenarios with 5 experts.
2	C. A. Collazos, C. Rusu, J. L. Arciniegas, S. Roncagliolo [74]	2009	Interactive Television (iTV)	1. Review design principles and guidelines for television and web. 2. Define basic principles for designing the iTV interface. 3. Propose a set of 14 heuristics for iTV.	Name, description	N/A
3	P. Jaferian, K. Hawkey, A. Sotirakopoulos, M. Velez-Rojas, K. Beznosov [12]	2011	IT Security Management (ITSM)	1. Understand the characteristics of ITSM tools. 2. Collect data from different sources: related work and interviews performed. 3. Analyze and identify explicit guidelines and recommendations for building ITSM tools, 4. Propose 7 heuristics for the usability evaluation of ITSM tools. 5. Evaluate the effectiveness of heuristics.	Heuristic Id, name, description, empirical support, interview snippets, discussion	– A controlled comparative heuristic evaluation, where the effectiveness of heuristics is compared to existing heuristics. – They conducted a post evaluation questionnaire to rate the evaluators experience in using heuristics. – They conducted either a focus group or an interview to collect qualitative data on participants' experience. – They compared the performance of the heuristics used in each condition according to their thoroughness, reliability, validity, effectiveness and discuss the cost-effectiveness. – They evaluated the impact of participants' background on their performance.
4	Y. H. Liao, C. Shen [75]	2012	Digital Learning Games	1. Collect information related to digital learning games, its features and game design elements. 2. Define usability heuristics based on guidelines grouped into 6 categories. 3. Refine and modify the heuristics based on feedback obtained from experts.	Id, name	N/A
5	Al-Razgan, Al-Khalifa and Al-Shahrani [76,104]	2012, 2014	Mobile Launchers for Elderly People	1. Convert previous guidelines and recommendation designs into usability problems. 2. Group similar usability problems into categories. 3. Create heuristics as interrogative sentences based on usability problems set in step 2 and other heuristics related.	Category, sub-category, questions (heuristics) as checklist	Experimental study (heuristic evaluation) aimed at assessing the appropriateness of the proposed heuristics.

Appendix H. Usability heuristics developed based on interviews

N°	Authors	Year	Domain	How heuristics were developed	Template used	Validation method
1	M. Brown [77]	2008	Computer Games	1. Gather data using a questionnaire (Critical Incident Technique). Questionnaire involves asking participants to describe exceptional incidents they encountered when playing a game. 2. Results obtained are divided into categories, selecting comments focused on usability. 3. Organize categories into 4 themes. 4. Create 13 usability heuristics based on categories developed and existing heuristics proposed by other researchers. 5. Evaluate the heuristics by a group of game design and usability experts. 6. Refine the heuristics (merge, re-word and add new heuristics, integrate the design principles and remove the categories-themes). 7. Propose the final set of 9 heuristics.	– Category, number, heuristic name – Final set: Number, name, description	Expert opinion. The 14 experts were asked to review the list of initial heuristics and comment on the individual heuristics and the heuristic set as a whole.
2	T. Hermann [78]	2009	Computer Supported Collaborative Creativity	1. Understand and overcome the problems that can occur when using CSCW-features for collaborative creative work. 2. Conduct and analyze interviews: prepared set of questions, identify significant categories, etc. 3. Formulate a set of heuristics with information collected in the interviews and literature reviews.	N/A	N/A
3	D. Katre, G. Bhutkar, S. Karmarkar [79]	2010	Touch Screen Ventilator Systems	1. Collect specific features related to ventilators system. 2. Conduct an interview with a physician with the required medical expertise. 3. Formulate 56 heuristics grouped into 7 categories. 4. Validate heuristics through heuristic evaluation.	Category, sub-category, Id, name, indicator	Heuristic evaluation with 4 evaluators.

Appendix I. Usability heuristics developed based on theories

N°	Authors	Year	Domain	How heuristics were developed	Template used	Validation method
1	T. Zuk, L. Schlesier, P. Neumann, M. S. Hancock, S. Carpendale [80,105]	2006	Information Visualization	1. Collect information about I. visualization. 2. Analyze theories and framework of I. visualization. 3. Review previous heuristics: Bertin's [107], Ware's [108] and Tufte' [109] heuristics. 4. Select 13 potential heuristics that are relevant to evaluate I. visualization.	Heuristic, source, relevance (1 to 8)	N/A
2	E. de Lera, M Garreta-Domingo [81]	2007	User's Affective Dimension	1. Review several theories that relate expressive reactions to distinct emotions. 2. Select a subset of features that make it possible to partially assess the emotional reaction of the users as they interacted with an application.	Number, name, description	User test with 8 participants. Four participants were assigned to carry out some tasks at an intentionally frustrating online supermarket, and 4 other participants were asked to carry out the same exact tasks at a much less frustrating online supermarket.

3. Correlate the emotional cues identified with an emotional state and ensure that these could be easily identified and measured during a user evaluation.
4. Define a list of 10 heuristics (emotional cues) that include some features that are not directly related to facial expressions.
5. Validate the set of heuristics.

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