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A methodology to develop usability/user experience heuristics

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ABSTRACT

Technology, software systems and human–computer interaction paradigms are evolving. Traditional usability heuristics do not cover all aspects of user–system interactions. Many sets of heuristics have been proposed, with the aim of evaluating specific application domains and their specific usability-related features. In addition, several sets of heuristics are used to evaluate aspects other than usability that are related to the user experience (UX). However, most authors use an informal process to develop usability/UX heuristics; there is no clear protocol for heuristic validation. This can result in sets of usability/UX heuristics that are difficult to understand or use; moreover, the resulting sets of heuristics may not be effective or efficient evaluation tools. This article presents a formal methodology for developing usability/user experience heuristics. The methodology was applied in practice in several case studies; it was also validated through expert opinions.

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 evaluated by usability inspections or usability tests. Usability is part of the User eXperience (UX). UX includes all the users' emotions, beliefs, preferences, perceptions, responses, behaviors and accomplishments that occur before, during and after using a product [2]. In addition to usability, there are several UX aspects that are important to evaluate in a software application.

Heuristic evaluation is a usability inspection method that is widely used to identify usability problems [3]. A set of evaluators judge the product interface to determine whether it satisfies usability principles [4]. This method uses "heuristic principles" or "usability heuristics" to evaluate usability.

Several authors have proposed many sets of heuristics for evaluating specific application domains and their specific features. This is because traditional heuristics do not evaluate specific features of specific applications. The many existing research works that are focused on designing new sets of heuristics indicates the interest and importance of creating heuristics for specific usability problems in specific application domains. In addition, several sets of heuristics are used to evaluate not only usability, but also other important aspects that are related to the UX, such as learnability, playability, and adaptability.

However, in most of the reviewed studies, there is no evidence that a formal process or methodology had been used to develop usability/UX heuristics [5]. This is because there are no theories or models that are appropriate for establishing heuristics for specific domains or for evaluating usability heuristics in terms of their applicability to a specific type of application. Most existing heuristics have been developed based on the researchers' experience or using methods that are usually employed for other purposes but adapted to create heuristics [6].

It is possible to summarize the development process of usability/UX heuristics in two stages: (1) extraction of information and (2) transformation of extracted information into heuristics [7]. However, there is no consensus about the most effective process for developing heuristics for specific application domains [8].

Many proposed usability heuristics are established as an extension or adaptation of existing heuristics (such as Nielsen's heuristics). The studies do not document or explain in detail the process that is followed to create the new set of usability heuristics. Most studies do not specify whether the process is formal or informal, or if the authors used a methodology for developing heuristics.

Although there are methodologies that support the process of developing usability heuristics [9–14], there is currently no clear protocol for heuristic validation. The whole process of developing usability heuristics has yet to be formalized [15]. In conclusion, there is no formal process for formulating, specifying, validating and refining usability/UX heuristics. To facilitate the process of developing heuristics, we propose a formal methodology with several stages for establishing usability/UX heuristics.

This document is organized as follows: Section 2 explores the theoretical background; Section 3 explains the need for a formal methodology for developing usability/UX heuristics; Section 4 shows the process that we followed to create the methodology; Section 5 presents the formal

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methodology for developing usability/UX heuristics; Section 6 explain briefly each stage of the methodology, including examples for the national park website domain; Section 7 presents the methodology's validation and results; and Section 8 presents the conclusions and future works.

2. Theoretical background

The concepts of usability, user experience, heuristic evaluations and evaluation methods are briefly presented below. In addition, related work is described.

2.1. Usability

As stated in the ISO 9241-11 standard, usability can be defined as follows [16]: "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".

This standard explains how to identify the necessary information to be considered when specifying or evaluating usability in terms of user performance and satisfaction [17]. The standard was updated and is still under review [1].

2.2. Usability evaluation methods

As Fernández et al. highlight, "a method of usability evaluation is a procedure composed by a series of well-defined activities for data recollection related to end user's interaction with a software product and/or how a specific feature of this software product contributes in achieving a certain degree of usability" [18]. Usability evaluations can be classified in two categories:

1. Usability inspections. These are revisions that are made by evaluators – usually experts – based on their own judgment, without the participation of users.
2. Usability tests. These are examinations that include real users, who evaluate a working software product.

Usability inspections are methods that are based on the participation of evaluators in inspecting interfaces [19], whereas usability tests are methods where a user or a group of users are asked to run a working system prototype and evaluate it with the objective of collecting information to improve the software product's usability [19].

2.3. Heuristic evaluation

A commonly used usability inspection method is heuristic evaluation. It identifies usability problems and "measures" the usability degree according to usability principles or usability heuristics. Heuristic evaluation was proposed by Nielsen and Molich [20]. Usability experts inspect a product (interface) based on heuristics to identify usability problems. The problems are classified (associated to the set of heuristics that is used) and rated (in terms of severity, frequency and critically).

2.4. Usability heuristics

Heuristic evaluation is performed based on a set of usability heuristics. They are called "heuristics" because they are more rules of thumb than specific usability guidelines [21]. Nielsen's 10 heuristics [21] are widely used to evaluate usability through heuristic evaluation. The set of Nielsen's heuristics is shown in Table 1.

Each system or application has features that differentiate it from other (types of) applications. For this reason, traditional heuristics may not assess unique features for specific domains, thereby neglecting important elements that must be evaluated. To effectively evaluate a specific domain, several authors have designed new sets of usability heuristics, by adapting Nielsen's heuristics and/or adding new heuristics to evaluate specific aspects.

Table 1
Nielsen's 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

2.5. User eXperience

UX extends the usability concept beyond effectiveness, efficiency and satisfaction. According to the ISO 9241-210 standard, UX can be defined as follows: "person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service" [2]. It states that UX "includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors and accomplishments that occur before, during and after use".

In addition, the ISO 9241-210 standard remarks that UX "is a consequence of brand image, presentation, functionality, system performance, interactive behavior and assistive capabilities of the interactive system, the user's internal and physical state resulting from prior experiences, attitudes, skills and personality, and the context of use" [2].

2.6. User eXperience evaluation methods

UX evaluation methods are focused on determining how users feel about the targeted software system [22]. UX evaluation allows designers to understand and gain insight into how users perceive and value products. Having this understanding will help in achieving positive UX and desirable products [23].

Depending on what one wants to evaluate, UX evaluation methods can be classified into four categories [24]: (1) field studies, (2) laboratories studies, (3) online studies, and (4) questionnaires and scales. Since UX extends the usability concept, some UX aspects may be assessed through usability evaluation methods, such as heuristic evaluation according to heuristics that cover some of the UX dimensions. However, evaluating all UX aspects is much more challenging. Performing user tests is very critical and important in evaluating UX.

2.7. Related work

Rusu et al. [9] propose a methodology with six stages for developing usability heuristics. This methodology has been used by several authors to create new sets of heuristics for specific application domains [25–38]. These authors emphasize that the methodology facilitates heuristic design and specification since it recommends stages that support the whole development process. In addition, the methodology suggests a template for specifying the heuristics and includes a validation and refining stage. However, some stages do not clearly explain what activities should be performed (specifically, the descriptive and correlational stages); it is not explained how, when, and under what circumstances to iterate the stages.

Van Greunen et al. [10] suggest a three-phase process for creating heuristics for specific application domains. This methodology has been used in one study to develop new heuristics [39]. The authors present a formal process for developing heuristics. Each stage is explained in detail, and the activities to be performed in each one are clearly described. However, the methodology lacks a specific explanation of how to specify heuristics (it does not propose any template), the validation stage does not clearly explain how to use the tool that is proposed by

the authors, and previous experience in using heuristics is not considered when selecting evaluators for the validation stage.

Hub and Čapková in [11] proposed a methodology for creating a suitable set of heuristics for a specific application domain: a public administration portal. The methodology has not been used in other studies. The authors consider different roles for the creation of heuristics: (1) experts for specification and revision of heuristics and (2) end users for evaluation and revision of the heuristics. The authors present an interesting structure of work, since they include different participants in the process of heuristic development and revision. However, they do not present a formal validation of heuristics. There are no details on how to validate heuristics or prove that they are effective.

Franklin et al. in [12] propose a methodology for establishing heuristics for a particular application: collaborative augmented reality remote systems. The methodology was created for developing heuristics for that specific application and has not been used in other studies. The authors propose a methodology for adapting existing heuristics and creating a new set of heuristics, including activities such as review, selection, deletion, fusion and adaptation. For validation, they propose using a focus group of Human–Computer Interaction (HCI) specialists (experts) to review the heuristics. Based on the obtained recommendations, the heuristics are refined. However, it is not explained in detail how to specify new heuristics since the proposed methodology is based mainly on adapting existing heuristics.

Lechner et al. [13] present a methodology for developing a set of usability heuristics. The methodology proposes two phases with different activities. Until now, this methodology has not yet been used to create new heuristics. The authors suggest a validation process that involves only real users, not evaluators (experts). In the first phase, the experts work together to define the new set of heuristics that are based on existing heuristics. Then, in the second phase, the heuristics are validated with users (users rate heuristics based on their perceived applicability). The methodology does not include experts in the validation process. However, final users may not have the knowledge to determine whether a heuristic is correctly specified or not. In addition, the phases are not iterative and a clear procedure for specifying and refining the heuristics is not proposed.

Hermawati and Lawson [14] suggest a methodology about how to expand heuristics sets for a specific application domain and validate them. The methodology is divided into two stages and includes users in the process of developing heuristics. Nevertheless, some activities are unclear, that is, information is lacking on how to perform certain actions: (1) the stages do not clearly explain the activities to be performed and in what order to perform them; (2) there is no explanation on how to define or specify the new heuristics (a template is not provided); (3) the authors do not indicate how to refine the set of heuristics after validation; (4) the validation methods that should be applied are not clearly proposed; and (5) there is no recommendation on the type of users that should participate in the validation process.

The reviewed methodologies present interesting, novel and useful approaches for developing heuristics. However, they lack formal specifications of stages and activities and most do not present a clear and well-defined process for validating the heuristics. In conclusion, there is still no methodology that proposes a formal and systematic process for specifying and validating usability/UX heuristics.

3. Need for a formal methodology

Several authors have stated that it is necessary to create new heuristics for evaluating specific applications. For example, in [40], the authors conclude that “the currently existing usability heuristics are too general to be applicable for evaluating the usability of mobile map applications”. Thus, it is necessary to develop a new set that evaluates the specific features of that domain. In [41], the authors observed that there were relatively small and inadequate sets of heuristics that could be used to evaluate Learning Management Systems, since these sets do not take into account the specific features of such systems (such as interface and didactic effectiveness). In addition, while existing heuristics may be used for evaluations of a specific application domain, these can be too generic and their applicability to the domain may be limited, which, in turn, may impair any evaluation that uses them [42].

As a result, specialized sets of heuristics are continually being developed and published [43]. This is mainly because the existing heuristics are too generic to evaluate specific aspects of a new application, system or device.

As Hermawati and Lawson indicate in [7], Nielsen's heuristics can be used to evaluate user interfaces for various domains, but the heuristics must be adjusted to ensure that specific usability issues of certain domains' user interfaces are not overlooked. Nielsen's heuristics allow a significant number of usability problems to be identified, but they do not address the specific aspects that a particular kind of software application can have [44]. For example, after performing an experimental evaluation in [45], the evaluators indicated that Nielsen's heuristics do not cover all usability aspects of a transactional web application.

When creating new heuristics, the authors follow different approaches. However, most studies do not document or explain (in detail) how the approach has been applied or the process that they followed to develop new heuristics [5]. Following a formal process is crucial for developing an effective and efficient set of heuristics.

Although there are methodologies that support the process of developing heuristics [9–14], there is currently no clear protocol for heuristic validation. The whole process of developing usability heuristics has yet to be formalized [15]. Based on the above, we propose a formal methodology for developing usability/UX heuristics and clearly identifying all stages to be followed to formulate, specify, validate and refine a new set of heuristics.

We refer to usability and UX heuristics, as it is possible to establish heuristics whose purpose is to evaluate relevant UX aspects other than usability, such as playability, learnability, and accessibility. We propose a methodology that allows the creation of different sets of heuristics, based on the aspects, factors or attributes to be evaluated.

4. Process of creating the methodology

We used several inputs to create the methodology and we performed two iterations to formalize, validate and refine it. The inputs that were used and the iterations that were performed are explained below.

4.1. Inputs for creating the methodology

Fig. 1 shows the 3 inputs that we used to create and formalize the methodology, which is the output of the whole process.

The methodology is based on results obtained in the following steps:

1. Systematic literature review: We conducted a systematic review of the processes that are followed in different studies to develop and specify usability heuristics, along with the methodologies that have been proposed for developing usability heuristics [5].
2. Experimental results: We performed several interviews and surveys to determine the perception of evaluators who were using Nielsen's heuristics in a heuristic evaluation [46]. In addition, the methodology of

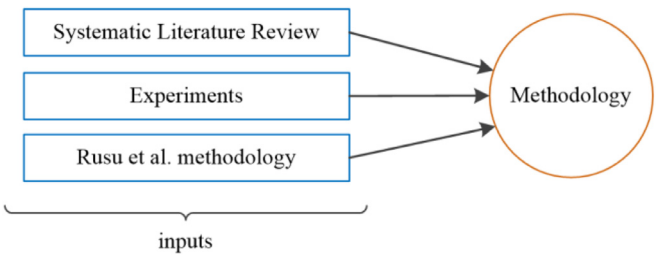

Fig. 1. Inputs for creating the methodology for developing usability/UX heuristics.

Table 2
Comparison between methodology that was proposed by Rusu et al. [9] and our methodology.

Step	Methodology of Rusu et al. [9]	Our methodology
Step 1: Exploratory stage	Collect bibliography for the main topics of the research: specific applications, their characteristics, and general and/or related (if identified) usability heuristics.	We improved the step definition. We included new types of information that must be collected, and we proposed information sources that can be reviewed.
Step 2: Experimental stage	–	New step. This step analyzes data that are obtained in experiments that were performed by other researchers that may provide additional information.
Step 3: Descriptive stage	Highlight the most important characteristics of the previously collected information, to formalize the main concepts that are associated with the research.	We improved the step definition. We explained in detail how to group the information that was collected in the previous stages and we proposed a three-level scale for prioritizing the grouped information.
Step 4: Correlational stage	Identify the characteristics that the usability heuristics for specific applications should have, based on traditional heuristics and case study analysis.	We refined and improved the step definition. We proposed to match application features, usability/UX attributes and existing heuristics to cover all these aspects with the new set of heuristics.
Step 5: Selection stage	–	New step. This step identifies the existing heuristics that can be used and/or adapted for the new set of heuristics, determines which existing heuristics can be discarded, and what heuristics should be created.
Step 6: Specification stage	Formally specify the set of proposed heuristics using a standard template. Template elements: ID, Name, Definition, Explanation, Examples, Benefits and Problems.	We refined and improved the step definition. We changed the name from "Explicative stage" to "Specification stage" (since the second term is clearer) and we added 5 new elements to the template.
Step 7: Validation stage	Check the new heuristics against traditional heuristics by experiments, through heuristic evaluations that are performed on selected case studies and complemented by user tests. The authors propose evaluating the set of heuristics in terms of the number of usability problems that are identified.	We refined and improved the step definition. We proposed an additional method for validating the new set of heuristics: expert judgment. Moreover, we added new elements to validate the effectiveness of the new set of heuristics through heuristic evaluations (5 criteria).
Step 8: Refinement stage	Refine the set of proposed heuristics based on the feedback from the validation stage.	We improved the step definition. We explained how to document the feedback that was obtained in step 7 (what heuristics to create, refine and/or delete, and why and how to do it, and what steps to repeat).

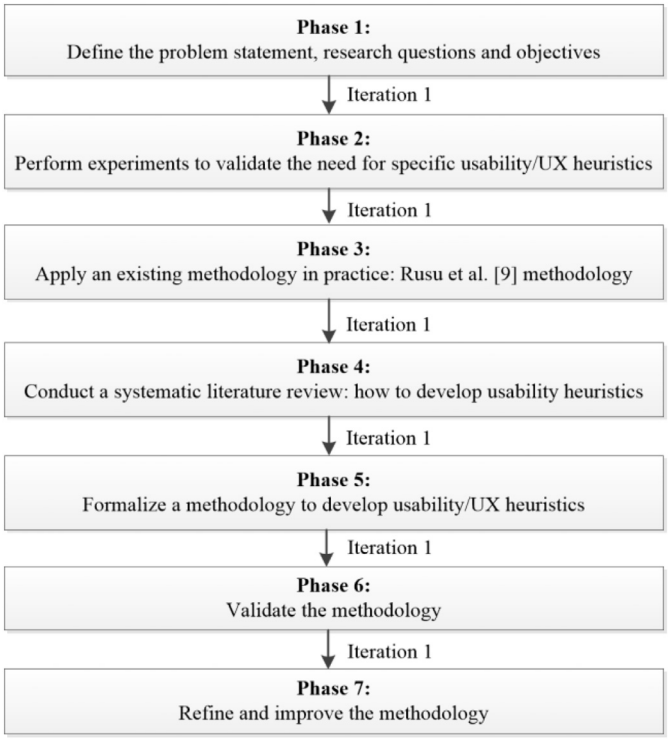

Fig. 2. Process of developing the methodology (first iteration).

Rusu et al. [9] was applied to create heuristics for transactional websites to detect deficiencies in the process of developing heuristics [47].

3. Methodology of Rusu et al.: The methodology is based on [9]. We applied the methodology of Rusu et al. in practice [47] and analyzed the process that was followed by the authors to create heuristics for grid computing applications [25]. We made several changes with the aim of improving the methodology that was proposed by Rusu et al. [9]. Table 2 shows a comparison between the methodology that was proposed by Rusu et al. [9] and our methodology, and details what has been added and/or improved.

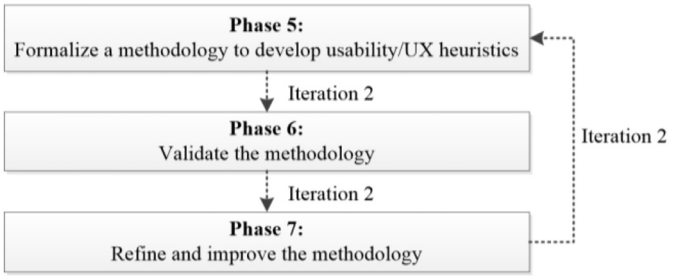

Fig. 3. Process for developing the methodology (second iteration).

The methodology was formalized at different levels through descriptions, tables and diagrams. We added new elements into the methodology specification: (1) we added BPMN diagrams to explain steps and activities (Appendices A–K) and (2) we included summary tables for each step to explain inputs, outputs and activities (Section 5).

4.2. Iterations

We performed two iterations to formalize, validate and refine the methodology. The process that we followed to create the methodology was divided into 7 phases.

4.2.1. First iteration

In the first iteration, all 7 phases were performed (see Fig. 2).

In phase 1, we defined the problem statement, research questions and objectives.

In phase 2, we performed several experiments to validate the need for specific usability/UX heuristics. We applied surveys and conducted interviews to determine if Nielsen's heuristics [21] are easy to understand for evaluators and allow the evaluation of all the (domain-related) features of a specific application. Experimental data show that Nielsen's heuristics present several problems in their definition [46] and that it is not possible to evaluate all the features of a specific application.

In phase 3, we applied the methodology that was proposed by Rusu et al. [9] to develop a new set of usability heuristics for transactional website applications [47]. We analyzed the methodology and its stages

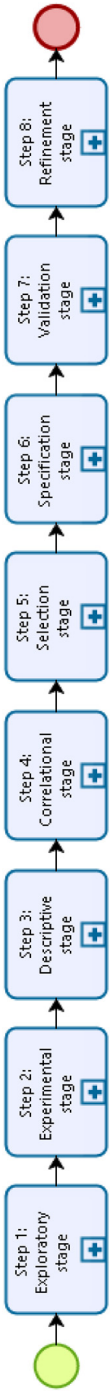

Fig. 4. BPMN diagram – stages of the methodology.

Table 3
Step 1: Exploratory stage.

Step 1: Exploratory stage: perform a literature review.	
What do I need to get started?	➪ A specific application domain that needs a new set of heuristics or checklist.
What to do?	Collect information about the specific application domain, their features, the usability/UX attributes that will be evaluated with the new set of heuristics, and the existing set of heuristics (and/or other relevant elements, such as principles, guidelines, and patterns).
What is obtained?	➡ ① Information about application (definitions and features). ➡ ② Usability and UX attributes. ➡ ③ Sets of heuristics and/or other relevant elements.

to identify potential deficiencies and suggest improvements.

In phase 4, we conducted a systematic literature review regarding the processes that are followed to develop and specify usability heuristics [5]. We analyzed different methodologies that have been proposed for creating heuristics and we concluded that they lack clear specifications of stages and activities and, especially, a clear procedure for heuristic validation [5].

In phase 5, we formalized a methodology for developing usability/UX heuristics. We made several changes with the aim of improving the methodology that was proposed by Rusu et al. [9] (see Table 2).

In phase 6, we performed a preliminary validation of an earlier version of the methodology, which is briefly described in [48]. The validation consisted of asking experts about what elements they would add, modify or remove to improve the methodology (see Section 6.1).

In phase 7, we refined the methodology based on the results and feedback that were obtained in the previous phase. All comments and recommendations were taken into account to improve the methodology (see Section 6.1).

4.2.2. *Second iteration*

In the second iteration, we performed a new validation and refinement of the methodology; phases 5, 6 and 7 were repeated (see Fig. 3).

In phase 5, we applied all the changes that were presented in phase 7 of the first iteration.

In phase 6, we conducted a survey of 9 usability/UX experts who applied the methodology to develop heuristics for several specific application domains. They were asked to evaluate each step of the methodology separately in 4 dimensions. We also included 5 questions that rate the methodology globally and 4 open questions that prompt qualitative comments (see Section 6.2).

In phase 7, we refined the methodology based on the expert opinions that were collected in phase 6. We analyzed all suggestions and we made changes accordingly (see Section 6.2). Section 5 presents the final version of the methodology.

5. Formal specification of the methodology to develop usability/UX heuristics

We created a methodology for developing usability/UX heuristics that includes 8 stages (see Fig. 4). The Business Process Model and Notation (BPMN) has been used to model each of the methodology's stages. BPMN provides a graphical notation for representing a business process as a diagram [49]. Appendices A–K show the BPMN diagrams for each stage of the methodology.

Although Fig. 4 shows sequentially the stages of the methodology, the development of heuristics may be performed iteratively. In specific situations (1), some stages may be optional, i.e., they are not performed for some reason; (2) some stages overlap, because it is necessary to perform two stages together; and (3) a stage may stop and one can to go back to an earlier stage.

We recommend applying the methodology iteratively. The iterations allow the improvement of the set of heuristics and the

Table 4
Step 2: Experimental stage.

Step 2: Experimental stage: analyze data that are obtained in different experiments to collect additional information that has not been identified in the previous stage.	
What do I need to get started?	➪ A specific application domain that needs a new set of heuristics or checklist. ■ The data can be obtained in previous experiments that were performed by other researchers. The obtained results will be related to specific features of the application, usability problems (both useful for Step 3: Descriptive stage) and problems with existing heuristics (useful for Step 6: Specification stage).
What to do?	■ If there are no previous data, it is possible to perform experiments to obtain them, as long as there is time and evaluators are available to participate. In the case that it is decided to perform an experiment, the experiment might consist of Heuristic Evaluation, Usability Test, Interview and/or Survey. Consideration: This step is optional. The researcher can decide whether to analyze the data of previous experiments or conduct new experiments to collect useful and complementary information.
What is obtained?	➡ ④ Additional specific features of the application ➡ ⑤ Detected usability problems ➡ ⑥ Problems with existing heuristics

Table 5
Step 3: Descriptive stage.

Step 3: Descriptive stage: select and prioritize the most important topics of all information that was collected in the previous stages.	
What do I need to get started?	➪① Information about the application (definitions and features) ➪ ② Usability and UX attributes ➪ ③ Sets of heuristics and/or other relevant elements ➪ ④ Additional specific features of the application (optional*) ➪ ⑤ Detected usability problems (optional*) * The necessity of this step depends on whether experiments were performed in Step 2
What to do?	1. Separate and group information according to the following topics: 1.1. Information about the specific application domain: definitions, classifications, context, areas of use and research justification. 1.2. Features of the specific application domain: elements that define the type of application (what the software product does and how it does it). 1.3. Usability and User Experience attributes: attributes that will be evaluated with heuristics. 1.4. Existing sets of heuristics and/or other relevant elements: traditional or specific sets of heuristics that were developed for similar applications and/or other elements that are relevant to the application (guidelines, patterns, and so on). 1.5. Usability problems detected (optional): problems identified by previous experiments. 2. Sort and prioritize the information of each topic according to the following scale: (3) highly important, (2) somewhat important, and (1) not important. If after reviewing the existing heuristics, it is determined that the identified set properly evaluates the specific application domain, the researcher can stop the process of developing heuristics and use this set of heuristics.
What is obtained?	➡ ⑦ Selected information about the application ➡ ⑧ Selected features of the specific application domain ➡ ⑨ Selected usability/UX attributes ➡ ⑩ Selected sets of heuristics and/or other relevant elements

Table 6
Step 4: Correlational stage.

Step 4: Correlational stage: match the features of the specific application domain with the usability/UX attributes and existing heuristics (and/or other relevant elements).	
What do I need to get started?	➪ ⑦ Selected information about the application ➪ ⑧ Selected features of the specific application domain ➪ ⑨ Selected usability/UX attributes ➪ ⑩ Selected sets of heuristics and/or other relevant elements
What to do?	■ Find a match among features, usability/UX attributes and existing heuristics (and/or other relevant elements). ■ The matching process should be guided by features. Attributes should be associated with each feature. Each feature should have at least one matching attribute. Then, each feature and attribute is matched with the existing sets of heuristics. ■ Determine whether heuristics will be classified into categories. Each category can group heuristics that evaluate certain specific aspects. It is recommended to create categories as it helps reduce the complexity of the information that is collected.
What is obtained?	➡ ⑪ Matched features, attributes and existing heuristics (and/or other relevant elements) ➡ ⑫ Categories

performance of new experiments to validate it. It is possible to repeat all stages, some stages, or only one stage of the methodology. The researcher may perform as many iterations as needed; the process is not always finalized with the Step 8: Refinement stage.

Each stage of the methodology is explained below. We present a summary table for each step, which shows the following: (1) definition of the stage; (2) the inputs that are needed to start the stage; (3) the activities that are performed in the stage; and (4) the outputs that are obtained at the end of the stage. The methodology is more extensive; however, to improve readability, a summarized version is presented (Tables 3–10).

6. Explaining the methodology

In this section, we briefly explain each stage of the methodology including examples for the national park websites domain.

6.1. Step 1: Exploratory stage

A review of the literature must be conducted to collect relevant information for developing the new set of heuristics. The researcher can review different information sources, such as scientific articles, theses,

Table 7
Step 5: Selection stage.

Step 5: Selection stage: keep, adapt and/or discard the existing sets of usability/UX heuristics that were selected in Step 3 (and/or other relevant elements).	
What do I need to get started?	➪ ⑩ Selected sets of heuristics and/or other relevant elements ➪ ⑪ Matched features, attributes and existing heuristics (and/or other relevant elements)
What to do?	For each heuristic, select one of the following options: 1. Keep the existing heuristic without any change: the heuristic is clear and correctly evaluates an aspect of the application and a usability/UX attribute. 2. Eliminate the existing heuristic: the heuristic evaluates aspects that are unrelated to the specific application. 3. Adapt the existing heuristic: the heuristic evaluates an aspect of the specific application and a usability/UX attribute, but changes are needed. It is also possible to combine two or more heuristics from different sets into a single heuristic. 4. Create a new heuristic: a new heuristic is required for evaluating a specific feature of the application (here, the heuristic is not created; it is only necessary to define the aspect for evaluation). Other relevant elements that were collected selected in Step 3 may be used to create a heuristic. Consideration: Eliminate redundant heuristics. Different sets may present similar or identical heuristics.
What is obtained?	➡ ⑬ Classified heuristics (to keep, adapt, create and eliminate)

Table 8
Step 6: Specification stage.

Step 6: Specification stage: formally specify the new set of usability/UX heuristics.	
What do I need to get started?	➪ ⑥ Problems with existing heuristics (optional)* ➪ ⑪ Matched features, attributes and existing heuristics (and/or other relevant elements) ➪ ⑫ Categories (optional)** ➪ ⑬ Classified heuristics (to keep, adapt, create and eliminate) * The necessity of this step depends on whether experiments were performed in Step 2. ** The necessity of this step depends on whether categories were defined in Step 4.
What to do?	1. Define the number of heuristics. 2. Group heuristics into categories (if deemed necessary). 3. Determine which elements to include in the heuristics' specifications (such as id, definition, examples, checklists, etc.). 4. Formally specify heuristics. We propose using the following template: ■ **Id:** Heuristic's identifier. ■ **Priority:** Value that identifies how important the heuristic is in the evaluation of a specific aspect or feature. The value can be (3) Critical: Heuristic evaluates a crucial aspect; (2) Important: Heuristic evaluates a relevant aspect; or (1) Useful: Heuristic further improves the usability/UX. ■ **Name:** Heuristic's name. ■ **Definition:** A brief but concise definition of the heuristic. ■ **Explanation:** Detailed explanation of the heuristic. ■ **Application feature:** Feature or aspect of the specific application domain that is evaluated with the heuristic. ■ **Examples:** Examples of violation of and compliance with the heuristic. Include an image that graphically explains the problem. ■ **Benefits:** Expected usability/UX benefits when the heuristic is satisfied. ■ **Problems:** Anticipated problems of heuristic misunderstanding. ■ **Checklist:** Items or criteria that are associated with the heuristic. ■ **Usability/UX attribute:** Usability/UX attribute that is evaluated with the heuristic. ■ **Heuristics related:** Set (or sets) of heuristics on which the heuristic is based, along with the authors and the references. Considerations: ■ We recommend that the average number of heuristics be between 10 and 16. ■ If it has been decided to group heuristics into categories, they must be specified in a coherent order. ■ If it is necessary to add a greater level of detail, it is suggested to develop a checklist.
What is obtained?	➡ ⑭ Set of proposed heuristics

Table 9
Step 7: Validation stage.

Step 7: Validation stage: validate the set of heuristics through several experiments in terms of their effectiveness and efficiency in evaluating the specific application.	
What do I need to get started?	➪ ⑭ Set of proposed heuristics
What to do?	Validate the set of heuristics through the following methods: 1. Heuristic evaluation: check the new set of heuristics against control heuristics (traditional or specialized heuristics) through heuristic evaluations. 2. Expert Judgment: check the validity of the proposed set of heuristics by asking to usability experts about their appropriateness for evaluating the specific application. 3. User Test: check whether the usability/UX problems that were identified in a heuristic evaluation using the new set of heuristics are usability/UX problems for users, and/or obtain the perceptions of users about a specific topic. Considerations: ■ We recommend always validating the set of heuristics through heuristic evaluation. ■ Expert judgment should be performed whenever possible, to receive additional feedback. ■ Complement the validation with user tests if necessary. ■ We recommend using more than one method to validate, to compare the results that are obtained by different methods.
What is obtained?	➡ ⑮ Heuristic evaluation results: effectiveness of heuristics ➡ ⑯ Expert judgment results (survey): utility, clarity, ease of use, need for checklist and comments about each heuristic ➡ ⑰ User tests results: users' perceptions

previous experiments (e.g., the results that were obtained in a heuristic evaluation), books, and websites (with reliable and credible information). Appendix A shows the BPMN diagram for Step 1: Exploratory stage.

6.2. Step 2: Experimental stage

This stage does not require additional explanations. Appendix B shows the BPMN diagram for Step 2: Experimental stage.

6.3. Step 3: Descriptive stage

The step aims at selecting and highlighting the most important topics of all information that was collected in the previous stage, to formalize the main concepts that are associated with the research. Appendix C shows the BPMN diagram for Step 3: Descriptive stage. Table 11 shows the information that was collected and selected for creating usability/UX heuristics for national park websites.

6.4. Step 4: Correlational stage

In the matching process, it is possible that there is no existing heuristic that evaluates a specific feature of the application domain. In this case, the researcher only matches the feature with the usability/UX attribute. In Step 5 (Selection stage), a new heuristic that covers that feature and attribute will be tentatively proposed. Appendix D shows the BPMN diagram for Step 4: Correlational stage.

As an example, Table 12 shows the matches among national park website features, usability/UX attributes, and the set of heuristics for virtual museums [52] that were selected in Step 3 (Descriptive stage). Some existing heuristics partially cover the features and attributes, while other features and attributes are not covered by any existing heuristics (this means that it is necessary to create new heuristics for evaluating these elements).

6.5. Step 5: Selection stage

Table 12, which was created in Step 4: Correlational stage, can support the heuristic selection process and be used to determine whether to keep, adapt or eliminate each heuristic. Those heuristics that were matched with a specific feature and usability/UX attribute may be taken into account in the development of the new set of heuristics. Appendix E shows the BPMN diagram for Step 5: Selection stage.

Table 13 shows some examples of the heuristic selection process for creating a new set of heuristics for national park websites. The entries in column “Applicability” indicate how important it is to consider the heuristic in the design of the new set. The applicability of the heuristic can have one of three values: (3) Critical, (2) Important, and (1) Useful (if included, much better). If a heuristic is eliminated, the last two columns of the table (“Aspect or feature covered” and “Applicability”) are left blank.

6.6. Step 6: Specification stage

The step requires the formal specification of the new set of usability/UX heuristics. We recommend keeping the number of heuristics relatively small (between 10 and 16). In the studies that were analyzed in the systematic review that develop new sets of heuristics [5], the authors create less than 20 heuristics. This is because it difficult to apply a large number of heuristics in practice. Appendix F shows the BPMN diagram for Step 6: Specification stage.

If it is necessary to add a greater level of detail, we suggest developing an additional checklist. A heuristic is a general rule. A heuristic evaluates a feature or specific aspect of an application. A checklist is more specific: it is a list of items that must be checked.

Table 14 shows a set of heuristics for national park websites that was developed using the methodology. Table 15 shows the complete template of heuristic NPH2: Multimedia resources.

6.7. Step 7: Validation stage

The step aims at validating the set of usability/UX heuristics. As it is a critical stage in the process, we detail the three types of validation that we propose. Experiments may be conducted to evaluate the effectiveness and efficiency of the new set of heuristics when evaluating the usability/UX of specific applications. Appendices G–J show the BPMN diagrams for Step 7: Validation stage.

6.7.1. Validation through heuristic evaluation

Perform a heuristic evaluation to evaluate the proposed set of heuristics against a set of control heuristics in specific case studies. For this, the researcher must carry out the following steps:

1. Select applications to evaluate: We recommend selecting a representative product for the specific application domain. For instance, for national park websites, a representative product should be the Yellowstone National Park Website (https://www.nps.gov/yell/index.htm).
2. Select the set of control heuristics: Control heuristics are a set of heuristics that will serve as the basis for comparing the results that were obtained in the heuristic evaluations. The researcher decides what set of control heuristics will be used for evaluation, according to the sets of heuristics that were identified in Step 1: Exploratory stage. If specific and/or related heuristics were not identified in Step 1, traditional Nielsen's heuristics [21] can be used as control heuristics. According to Anganes et al. [43], five attributes must be present in a set of specialized heuristics to determine their confidence: (1) Basis, (2) Validation, (3) Ease of learning, (4) Ease of use, and (5) Fit.
3. Select evaluators for heuristic evaluation: The selected specific application is evaluated by two separate groups of evaluators of similar experience under the same conditions (both groups evaluate the same product). One group uses only the set of heuristics that were defined in Step 6: Specification stage (called the Experimental group), while the second group uses only the set of control heuristics (called the Control group). The groups work separately. Then, the usability/UX problems that are identified by the two groups are compared. Evaluators should have similar experience conducting heuristic evaluations to obtain reliable results and eliminate external factors that may contaminate the experiment. Different levels of experience generate different results.
4. Evaluate the effectiveness of the heuristics based on the results that were obtained in the heuristic evaluations. To evaluate the effectiveness of heuristics, we recommend comparing the problems that were identified by both groups in terms of 5 criteria:
5. Numbers of correct and incorrect associations of problems to heuristics.
6. Number of usability/UX problems that were identified.
7. Number of specific usability/UX problems that were identified.
8. Number of identified usability/UX problems that qualify as more severe.
9. Number of identified usability/UX problems that qualify as more critical.
10. The new set of usability/UX heuristics performs well and it is an effective instrument when better results than the control heuristics are obtained in terms of (1), (2), (3), (4) and (5).

6.7.2. Validation through expert judgment

"Expert Judgment" is a term that refers to a technique in which the judgment of a person is based on their knowledge and experience in a specific area. We suggest asking experts about the usefulness, efficiency and effectiveness of heuristics to evaluate the usability of a specific application domain. In this case, the experts are divided in two groups: Researchers and Practitioners.

The Researchers are experts in HCI, usability and/or UX; they have experience designing or validating new sets of heuristics. The

Table 10
Step 8: Refinement stage.

Step 8: Refinement stage: refine and improve the new set of heuristics based on the feedback that was obtained in Step 7.	
What do I need to get started?	➪ ⑮ Heuristic evaluation results: effectiveness of heuristics ➪ ⑯ Expert judgment results (survey): utility, clarity, ease of use, need for checklist and comments about each heuristic ➪ ⑰ User tests results: users' perceptions (optional)* * The necessity of this step depends on whether this validation was performed in Step 7.
What to do?	1. Document the problems that arose when using the set of proposed heuristics and the changes that should be made. 2. Define the heuristics to be created, refined and/or deleted, why, and how to do it. 3. Iterate and apply some stages again, if necessary.
What is obtained?	➡ ⑱ Refining document: 1. What heuristics to create, refine and/or delete, why, and how to do it 2. What steps to repeat

Table 11
Information that was collected and selected for creating usability/UX heuristics for national park websites.

Topic	**Collected information**	**Selected information**
1. Information about national park websites	Definitions of national parks (physical place) that were proposed by 4 different authors, their purpose and research justification (why it is necessary to create a new set of heuristics for national park websites).	There is no formal definition of national park websites, only definitions of national parks as physical locations. Thus, based on the literature review, a definition has been proposed for applications of this type.
2. Features of the national park websites (general and specific features)	■ General features (crosswise features for any kind of software product that are also related to national park websites): 1) Feedback, 2) Visibility of contents, 3) Ease of navigation, 4) Error prevention, 5) Quick access, 6) Minimize the user's memory load, 7) Help for the user, and 8) Standards.	All general features were selected.
	■ Specific features (features of national park websites, which differentiate them from other types of software products): 1) Updated information, 2) Virtual experience, 3) Multimedia resources, 4) Permissions, restrictions and recommendations, 5) Information credibility, 6) Asynchronous interaction, 7) Useful and interesting content, 8) Multi-language content, and 9) Connectivity with social networks.	All specific features were selected except *Connectivity with social networks,* since it is not related to national park websites.
3. Usability and UX attributes	■ Usability attributes that were proposed by the ISO standard [16]: effectiveness, efficiency and satisfaction.	The 5 usability attributes that were proposed by Nielsen were selected since they are more complete than those that were proposed by the ISO standard.
	■ Usability attributes that were proposed by Nielsen [50]: learnability, efficiency, memorability, errors and satisfaction.	Six factors that were proposed by Morville were selected (useful, usable, desirable, findable, credible and valuable). *Accessible* was not considered, as the evaluation accessibility is not intended with the new heuristics.
	■ UX factors that were proposed by Morville [51]: useful, usable, desirable, findable, credible, accessible and valuable.	
4. Existing sets of heuristics	■ Nielsen's 10 heuristics [21]. ■ Heuristics for virtual museums (15 heuristics) [52]	The set of heuristics for virtual museums [52] was selected. Nielsen's heuristics [21] were discarded because they are too generic and do not cover some specific features of national park websites. Virtual museum heuristics were developed based on Nielsen's heuristics, by adapting the generic aspects to the context of the application, which is similar to national park websites.

Table 12
Matches among national park website features, usability/UX attributes and existing heuristics.

Feature	**Attribute**	**Heuristic**
Updated information	- Satisfaction (usability)	
- Useful, credible, valuable (UX)		–
Virtual experience	- Satisfaction (usability)	
	- Desirable, valuable, findable (UX)	VMH2: Visualization (partially covered)
Multimedia resources	- Satisfaction (usability)	
	- Desirable, valuable, findable (UX)	VMH6: Resources and connections (partially covered)
Permissions, restrictions and recommendations	- Satisfaction (usability)	
- Useful, usable, findable (UX)		–
Credibility in the information	- Satisfaction (usability)	VMH1: Visibility of system status (partially covered)
	- Useful, credible, valuable (UX)	VMH14: consistency and standards (partially covered)
Asynchronous interaction	- Satisfaction (usability)	VMH15: Synchronous and/or asynchronous interaction (partially covered)
	- Useful, valuable (UX)	
Useful and interesting content	- Satisfaction (usability)	
	- Useful, usable, findable (UX)	–
Multi-language content	- Learnability (usability)	VMH4: Match between the system and the real world (partially covered)
	–Useful, usable, credible (UX)	–

Table 13
Heuristic selection process.

ID	Heuristic name/explanation	Action	Set of existing heuristics	Aspect or feature covered	Applicability
VMH1	Visibility of system status	Adapt	[52]	Feedback of processes or changes (general feature)	(1) Useful
VMH2	Visualization	Adapt	[52]	Adequate visibility of contents, virtual experience (general and specific feature)	(2) Important
VMH3	Cultural learning	Eliminate (heuristic not related to national park websites)	[52]	–	–
N2	The website should present information that generates interest in the users. The user should understand how to use sections of the website.	Create	–	Useful and interesting content (specific feature)	(3) Critical

Table 14
Set of usability/UX heuristics for national park websites.

ID	Name
NPH1	Visibility of system
NPH2	Multimedia resources
NPH3	Information of interest
NPH4	Match between system and the real world
NPH5	User control and freedom
NPH6	Consistency and standards
NPH7	Information credibility
NPH8	Error prevention
NPH9	Minimize the user's memory load
NPH10	Flexibility and efficiency of use
NPH11	Aesthetic and minimalist design
NPH12	Help the user recover from errors
HPN13	Help and documentation
HPN14	Asynchronous interaction

Practitioners are experts conducting heuristic evaluations and they know how to correctly use a set of heuristics to find usability/UX problems. The activities to perform are as follows:

1. Select participants for Expert Judgment: We recommend including Researchers and Practitioners for expert judgment. This is because it is possible that an expert in HCI (Researcher) is not an expert in conducting a heuristic evaluation (Practitioner). It is important to have both points of view to validate the heuristics. It is important to mention that an expert can be a Researcher and a Practitioner at the same time. If possible, it would also be useful to include experts in the specific application domain. This is because it is possible that an expert in HCI is not expert in the specific application domain. It is important to have both points of view to verify that all the specific features of the application are covered and are evaluated with the newly proposed set of heuristics. In addition, we recommend that at least three experts validate the new set of heuristics.
2. Perform the expert judgment through survey: We propose using a questionnaire that assesses evaluators' perceptions of the new set of usability/UX heuristics, concerning 4 dimensions and 3 questions:
   - D1 – Utility: How useful the usability/UX heuristic is.
   - D2 – Clarity: How clear the usability/UX heuristic is.
   - D3 – Ease of use: How easy it was to associate identified problems with the usability/UX heuristic.
   - D4 – Necessity of an additional checklist: How necessary is it to complement the usability/UX heuristic with a checklist.
   - Q1 – Easiness: How easy it was to perform the heuristic evaluation, based on this set of usability/UX heuristics?
   - Q2 – Intention: Would you use the same set of usability/UX heuristics when evaluating similar software products in the future?
   - Q3 – Completeness: Do you think the set of usability/UX heuristics covers all usability aspects for this type of software product?

The set of usability/UX heuristics is rated globally through the 3 questions, but each heuristic is rated separately, on each of the 4 dimensions. All experts are asked to rate each usability heuristic, on each of the 4 dimensions, using a 5-point Likert scale. The value 1 indicates that the heuristic does not comply with the dimension and the value 5 indicates that the heuristic fully complies with the evaluated dimension. The 3 questions aim at evaluating the evaluators' overall perceptions; responses are also based on a 5-point Likert scale. The results of applying the survey that we propose are documented in [53–55].

6.7.3. Validation through user test

The user test is a complementary validation to the two validations that were previously discussed. Depending on the results that were obtained in the heuristic evaluation, it may be necessary to analyze these results from the perspective of the user. The user test can be useful for performing the following tasks:

1. Check if the usability/UX problems that were identified in the heuristic evaluation using the new set of heuristics are usability/UX problems for users.
2. Determine why the experimental group did not detect some of the problems that were detected by the control group. The tasks to be performed in the user test should involve the problems that were not detected by the experimental group, to determine why they were not detected.
3. Obtain the perceptions of users regarding a specific topic (for example, what features they consider relevant for the specific application domain).

6.8. Step 8: Refinement stage

Table 16 shows some examples about how to document the heuristics to be refined, eliminated and/or created based on the set of usability/UX heuristics for national park websites. Appendix K shows the BPMN diagram for Step 8: Refinement stage.

7. Validating the methodology

We performed the methodology validation in two iterations. HCI experts and researchers participated in both iterations. Each participant was given the full methodology specification, which was divided into two parts: a brief version and a detailed version. The validation's objective was to obtain feedback from experts and researchers to improve the methodology.

7.1. First iteration: validation through expert opinion

In the first iteration, a validation was performed on an earlier version of the methodology. This first validation consisted of asking an expert and five researchers what they think about the proposed methodology. All the participants have experience performing heuristic evaluations and using sets of usability heuristics, so they can give their points of view regarding whether the methodology is correctly specified, whether it is useful, and what elements they would add or remove, among others.

In this first validation, the following were obtained:

1. A review of the methodology by an HCI expert.
2. Comments and suggestions from five researchers who have used (and continue to use) the methodology to create new sets of heuristics.

Based on the obtained feedback, the methodology was refined. All the comments and recommendations were taken into account to improve the methodology. The improvements that were suggested by both the expert and the researchers and the actions that were taken are presented in Table 17.

7.2. Second iteration: validation through expert judgment

The methodology was recently applied in several case studies: on-line travel agencies, mobile apps for on-line travel agencies, parliamentary websites, websites for national parks, social networks, secure software systems, and 3D First Person Shouter (FPS) videogames. Sets of specific (usability/UX/playability) heuristics were developed in several iterations by 9 usability/UX experts. None of them had previous experience in developing sets of heuristics, but they were all familiar with the methodology that was proposed by Rusu et al. [9].

Based on the quantitative and qualitative results that were obtained, the methodology has been improved. Some of the comments and suggestions have been implemented, while others were not considered. The explanation of the changes that were made (and those that were not) is detailed below.

7.2.1. Survey

In the second iteration, we conducted a survey of 9 experts. They were asked to evaluate each step of the methodology separately, using a Likert scale of 5 levels (1 – worst to 5 – best) in 4 dimensions (D1, D2, D3, and D4):

- (D1) *Utility* – how useful the step is considered.
- (D2) *Clarity* – how clearly the step's specification is perceived.
- (D3) *Ease of Use* – how easy it is to perform the step.
- (D4) *Necessity for More Details* – how necessary it is to provide more details for the step's specification.

The survey included 5 questions (Q1, Q2, Q3, Q4, and Q5) that rate the methodology globally using the same type of Likert scale as for dimensions D1 to D4:

- (Q1) *Easiness* – how easy was it to develop the set of heuristics using the methodology?
- (Q2) *Overall Utility* – does the methodology facilitate the development of new heuristics?
- (Q3) *Intention of Future Use* – how probable is it that the methodology will be used when developing future sets of heuristics?
- (Q4) *Completeness* – does the methodology cover all aspects of the development of new heuristics?
- (Q5) *Additional Graphics* – is a more-detailed graphical specification of the methodology required for better understanding?

Additionally, 4 open questions were asked to obtain qualitative comments:

- (C1) – What specific aspects of the methodology were most difficult to apply in practice?
- (C2) – What elements, tasks or explanations do you think are missing and should be included?
- (C3) – What elements, tasks or explanations do you think are overemphasized (too many details are given)?
- (C4) – Do you think the methodology should include any additional steps? If so, for what purpose?

7.2.2. Quantitative results

Table 18 summarizes the results of the survey for dimensions D1 to D4. Descriptive statistics are analyzed below.

(D1) *Utility*. The average utility is high (4.68). Step 6 (Specification stage) is considered the most useful; all experts evaluated its utility with the highest score (5). Step 2 (Experimental stage) is considered "less" useful; however, its average utility is quite high (4.0). The standard deviation is relatively low (and the lowest among the 4 dimensions); it ranges from 0 (Step 6) to 0.73 (Step 2). The methodology's perceived utility is remarkably high; the lowest perceived utility is still high (Step 2).

(D2) *Clarity*. The average specification clarity is also high (4.40); it ranges from 3.89 (Step 4, Correlational stage) to 4.89 (Step 1, Exploratory stage). The standard deviation ranges from 0.33 (Step 1) to 1.05 (Step 2, Experimental stage, and Step 4, Correlational stage). The methodology's perceived clarity is high. Step 4 is perceived as the least clear step. Thus, the specification of this stage has been improved.

(D3) *Ease of Use*. The average ease is use is reasonable (3.61); it ranges from 3.11 (Step 4, Correlational stage) to 4.33 (Step 1, Exploratory stage). The lowest standard deviation occurs for Step 3 (Descriptive stage). For all other steps, the standard deviation is relatively high (ranging from 0.73 to 0.93). Step 4 is perceived as the most difficult to perform.

(D4) *Necessity for More Details*. The necessity for more details is low (average 2.64); its lowest value corresponds to Step 1 (Exploratory stage) and the highest values correspond to Step 4 (Correlational stage) and Step 5 (Selection stage). The standard deviation is high, from 0.93 (Step 1, Exploratory stage) to 1.80 (Step 4, Correlational stage). The experts' opinions on dimension D4 are heterogeneous.

The experts' opinions are approximately homogeneous for all dimensions, except D4. Step 4 (Correlational stage) is perceived as the least clear and most difficult to perform step, and it its specification is perceived to require more details (D4). For this reason, Step 4 has been modified to improve its definition and ease of use. Step 1 (Exploratory stage) scores the best in terms of perception in dimensions D2, D3, and D4; its specification

Table 15
HPN2: multimedia resources heuristic.

ID	**NPH2**
Priority	(3) Critical
Name	**Multimedia resources**
Definition	The website should be attractive to the user by providing a virtual experience when navigating through different multimedia resources.
Explanation	Multimedia resources such as images, videos and audios must be present on the national park websites, display the information in different ways and complement one another.
Application feature	Specific feature: multimedia resources. The heuristic aims at evaluating the existence of multimedia resources, which contribute to the website and improve the virtual experience when navigating through it.
Examples	Several images may document the use of multimedia resources.
Benefits	The satisfaction of the user increases when he or she finds different multimedia resources that complement one another and improve the virtual experience.
Checklist	1. All multimedia resources are available for viewing. 2. The website provides images, videos and/or interactive audios that complement one another and convey the contents of the national parks. 3. The website uses multimedia resources to capture the user's attention and make the user want to navigate the physical parks. 4. The website offers complementary options that work correctly, such as print, zoom, and download.
Usability attributes	Satisfaction
UX factors	Findable, Desirable, Valuable
Set of heuristics related	Heuristics for virtual museums [52].

Table 16
Heuristics to create, refine and/or eliminate (why and how to do it).

Heuristic	Problem	Action
NPH2 (*Content display*)	The definition of NPH2 is similar to that of NPH15 (*Aesthetic and minimalist design*).	Eliminate. NPH15 covers the same feature as NPH2.
NPH15 (*Aesthetic and minimalist design*)	The definition of NPH15 is similar to that of NPH2 (*Content display*).	Adapt. NPH15 should be complemented with the information that is detailed in NPH2 (*Content display*).
NPH5 (*Match between system and the real world*)	Half of the problems that were detected in the heuristic evaluation were incorrectly associated.	Adapt. The specification should be improved. In addition, the evaluation of multiple languages must be included.

is clear, additional details are not needed, and it is easy to perform.

The overall perception of the methodology (questions Q1–Q5) is presented in Table 19. We observe the following:

- On Easiness (Q1), it scored the lowest (average of 3.44) and had the most heterogeneous perceptions (standard deviation of 0.88); applying the methodology in practice is not a trivial task.
- On Overall Utility (Q2), it obtained the highest score (average of 4.89). The experts' opinions are remarkably positive; they think the methodology facilitated their work.
- The Intention of Future Use (Q3) score is remarkably high (average of 4.78); experts think it is very likely that the methodology will be used when developing new sets of heuristics.
- The methodology's Completeness (Q4) is perceived as reasonable (average of 3.78). Only one expert gave it a low rating (2); the other 8 experts gave it a high rating (4).
- On the need for Additional Graphics (Q5), an average score of 3.78 was obtained. The same expert that rated the methodology's Completeness as low (2) also rated as low (2) the need for Additional Graphics.

Even if the experts think that applying the methodology is not easy, they perceived it as useful and intend to use it in the future. The methodology's specification is perceived as fair, but the experts think that additional graphics would help.

As no assumption of normality could be made, the survey results were analyzed using nonparametric statistical tests. In all tests, $p \leq 0.05$ was used as the decision rule.

The Friedman test was performed to detect differences among experts' perceptions of the 8 steps of the methodology. The results (Table 20) indicate the following:

- The methodology's steps are not perceived as equally useful (D1), nor as equally easy to perform (D3).
- The steps' specifications are perceived as similarly clear (D2); the need for more detailed specifications (D4) is also perceived similarly for all steps.

The Spearman ρ test was performed to check the hypothesis:

H_0: $\rho = 0$, the dimensions/questions Dm/Qn and D/Qn are independent.
H_1: $\rho \neq 0$, the dimensions/questions D/Qm and D/Qn are dependent.

Table 21 shows the following:

- Most correlations are non-significant at the 0.05 level (marked as "N").
- There is a very strong significant correlation between D2 – Clarity and Q1 – Easiness; when steps' specifications are perceived as clear, the methodology is perceived as easy to apply in practice.
- There is also a very strong significant correlation between D3 - Ease of Use and Q1 – Easiness; when the methodology's steps are perceived as easy to perform, the methodology is perceived as easy to apply.
- There is a strong significant correlation between D3 – Ease of Use and Q3 – Intention of Future Use; when the methodology's steps are perceived as easy to perform, experts express their intention to use the methodology in the future.
- There is an unexpected very strong significant correlation between Q4 – Completeness and Q5 – Additional Graphics. When experts think that the methodology covers all aspects of the development of new heuristics, they still feel the need for more-detailed graphic specifications.

The few significant correlations that occur are (very) strong. Most of them are expected. The only unexpected correlation is between Q4 and Q5: when the methodology is perceived as complete, the experts still feel that additional graphics could help facilitate understanding. The perceived need for additional graphics could be due to the experts' backgrounds (engineering, computer science).

Table 17
Improvements that were suggested by both the expert and the researchers.

Step	Comment	Action
Methodology in general	It was not suggested to add any stage to or eliminate any stage from the methodology. The expert suggested indicating at each stage the inputs and outputs. Although these are shown in the BPMN diagrams (as input and output objects), it is recommended that this information also be detailed in the description of each stage.	We clearly included the inputs ("What do I need to get started?") and outputs ("What is obtained?") for each stage.
Step 1: Exploratory stage	The expert suggested that at this stage, the information about usability/UX attributes must be collected. The new set of heuristics must evaluate both features of the specific application domain and attributes of usability/UX.	This component is very important for the creation of heuristics, so it has been added at this stage. In addition, it is fundamental to perform Step 4: Correlation stage.
Step 2: Experimental stage	Both the expert and the researchers indicated that this stage is not understood very well.	We improved the description of step 2 and we clearly explained its purpose: analyze and interpret previous experimental data to obtain useful information for creating the heuristics. In addition, we clearly explained that if there is time and evaluators are available, it is possible perform additional experiments. Otherwise, it is not recommended to perform them.
Step 3: Descriptive stage	The expert recommended defining a mechanism for prioritizing the information that was collected in Step 1. The expert proposed creating a "relevance scale" for the information.	We included a three-level scale for prioritizing the information that is collected in Step 3.
Step 4: Correlational stage	The expert advised explaining clearly and with examples the objective of this stage, since the definition is confusing.	We improved the step specification. This step consists of matching among features, usability/UX attributes, and existing heuristics. We also included examples to explain the matching process.
Step 5: Selection stage	Both the expert and the researchers indicated that there is a lack of explanation on how to document the selected heuristics. Although a standard table is proposed for documenting the selection of heuristics, with which information to complete the table and what to do in particular situations should be clearly explained.	We improved the step specification as follows: – We explained how to document deleted heuristics (and what information to include). – We indicated that it is possible to combine two or more heuristics into a single heuristic. – We clearly indicated that it is important to eliminate redundancy (multiple sets that have the same heuristics should not be included in the selection process).
Step 6: Specification stage	The expert suggested adding two new elements to the template for specifying heuristics: – Application feature (justification): The aspect or feature of the specific application domain that each heuristic evaluates should be indicated. – Usability/UX attribute: The usability/UX attribute that each heuristic evaluates should be indicated, to cover both aspects of the specific application domain and usability/UX attributes in the definition of the heuristic.	We added two new elements to the template for specifying heuristics: Application feature and Usability/UX attribute.
Step 7: Validation stage	The expert recommended clearly indicating that it is important to perform more than one validation to obtain more feedback, so that it will be possible to compare and/or complement the results. For "Validation through Heuristic Evaluation", the expert suggested the following: – Use the term "control heuristics" rather than "traditional heuristics" since it is possible to create new sets based not only on Nielsen heuristics but also on other existing sets of heuristics. – Explain the scales of severity, frequency and criticality that are used. In addition, clearly indicate that these are suggested scales and that the researcher can decide which scales to use and, based on them, adapt the presented formulas. For "Validation through Expert Judgment", the expert proposed the following: – Explain clearly the types of experts that it is possible to survey and how to select them. – Explain how to analyze and interpret the results that are obtained in the surveys.	All the suggestions were taken into account. We improved the step specification.
Step 8: Refinement stage	The expert recommended including the feedback that is obtained from Step 7: Validation stage, to clearly determine what to refine and what steps should be repeated (if it is decided to iterate).	We clearly show the inputs for step 8 (outputs of step 7).

As dimensions D1, D2, D3 and D4 have been evaluated for each step of the methodology separately, we also performed the Spearman ρ test for each step. Only three significant correlations occurred:

- For Step 4 (Correlational stage), a strong negative correlation (−0.771) between D2 – Clarity and D4 – Necessity for More Details; when Step 4 is perceived as less clear, the experts think its specification requires more details.
- For Step 6 (Specification stage), a strong correlation (0.719) between D2 – Clarity and D3 – Ease of Use; when Step 6 is perceived as clear, it is also perceived as easy to perform.
- For Step 7 (Validation stage), a very strong correlation (0.804) between D1 – Utility and D2 – Clarity; when Step 7 is perceived as clear, it is also perceived as useful.

7.2.3. Qualitative results

When asked about specific aspects of the methodology that were most difficult to apply in practice (C1), the experts indicated the following:

- It is difficult and time-consuming to match usability/UX attributes and domain-specific characteristics (Step 4, Correlational stage; 5 comments). If done inadequately, the set of heuristics will not be suitable their purpose. Step 4 has been clarified. The methodology that is presented in Section 5 is the final version after this refinement.

Table 18
Survey results for dimensions D1, D2, D3 and D4.

		Step 1 – Exploratory stage	Step 2 – Experimental stage	Step 3 – Descriptive stage	Step 4 – Correlational stage	Step 5 – Selection stage	Step 6 – Specification stage	Step 7 – Validation stage	Step 8 – Refinement stage	Mean
D1 – Utility	Mean	4.89	4.00	4.67	4.44	4.89	5.00	4.78	4.78	4.68
	Std. dev.	*0.33*	*0.71*	*0.50*	*0.73*	*0.33*	*0.00*	*0.44*	*0.44*	
D2 – Clarity	Mean	4.89	4.11	4.44	3.89	4.22	4.56	4.56	4.56	4.40
	Std. dev.	*0.33*	*1.05*	*0.53*	*1.05*	*0.97*	*0.73*	*0.73*	*0.73*	
D3 – Ease of Use	Mean	4.33	3.44	4.00	3.11	3.33	3.78	3.44	3.44	3.61
	Std. dev.	*0.87*	*0.88*	*0.50*	*0.93*	*0.87*	*0.83*	*0.73*	*0.73*	
D4 – Necessity for More Details	Mean	2.11	2.56	2.44	3.00	3.00	2.67	2.44	2.89	2.64
	Std. dev.	*0.93*	*1.33*	*1.42*	*1.80*	*1.00*	*1.22*	*1.24*	*1.17*	

Table 19
Survey results for questions Q1, Q2, Q3, Q4 and Q5.

	Q1 – Easiness	Q2 – Overall utility	Q3 – Intention of future use	Q4 – Completeness	Q5 – Additional graphics
Mean	3.44	4.89	4.78	3.78	3.78
Std. dev.	0.88	0.33	0.44	0.67	0.67

Table 20
Friedman test results.

Dimensions	D1 – Utility	D2 – Clarity	D3 – Ease of use	D4 – Necessity for more details
p-Value	0.040	0.148	0.024	0.171

- Heuristic specification (Step 6, Specification stage) has to be performed carefully (2 comments). It requires details, precision, time, reviews, and (independent) validations. If not, the heuristics will be difficult to understand and apply in practice.
- Performing usability tests, as suggested in Step 7 (Validation stage), requires substantial time and resources (1 comment).
- When performing Step 5 (Selection stage), it was difficult to determine what aspect(s) a heuristic covers (1 comment).
- Step 1 (Exploratory stage) requires time and substantial information for its implementation (1 comment). However, the expert acknowledges that the step is critical.

When asked about what other elements, tasks or explanations the methodology should include (C2), the experts made a few comments. Table 22 shows the experts' comments, whether the suggestion has been taken into account, why and what changes have been made (when applicable).

When asked whether any elements, tasks or explanations are overemphasized in the methodology's specification by providing too many details (C3), most of the experts indicate that this is not the case. They also think that specifying the methodology in two forms (a brief form and a detailed form) is helpful. Only two comments mention that many details are given in some cases (Step 1: Exploratory stage, Step 2: Experimental stage, and Step 7: Validation stage); however, the two experts also admit that the nature of those steps requires detailed specifications.

When asked if the methodology should include any additional steps (C4), all experts agree that the methodology is complete.

The experts' comments are positive. They think the methodology is complete and offers the appropriate level of detail. They also highlight that offering two levels of details (a synthetized specification and a detailed specification) help researchers with different levels of expertize (in developing heuristics) better understand the methodology. Some suggestions were made and have already been implemented. The methodology was refined based on the experts' opinions, especially Step 4 (Correlational stage).

8. Conclusions

Heuristic evaluation is one of the most popular inspection methods [43]. Several sets of usability/UX heuristics have been developed for specific application domains, for evaluating both general and specific features. The heuristics should be well-designed, easy to use, and make it possible to identify domain-related usability/UX problems.

Following a methodology when specifying and validating heuristics makes development easier since it provides well-defined steps and proposes methods for validating new heuristics. If no methodology for developing heuristics is used, the created heuristics may be (1) difficult to understand, (2) difficult to use, and/or (3) not effective in evaluating the usability/UX of a specific application.

The methodology that was proposed by Rusu et al. [9] has been used to develop several sets of heuristics for specific applications. However, this methodology has deficiencies in explaining stages and generates confusion on how to iterate and apply it properly. Therefore, we develop a new methodology by making several changes to methodology that was proposed by Rusu et al. [9], namely, adding new steps, definitions and diagrams and improving the specification of the methodology. The new methodology presents tables that summarize the inputs, outputs and activities to be performed at each stage. We also included BPMN diagrams for each stage.

Two validations were performed to validate and refine the methodology. Most of the comments and suggestions from the experts were

Table 21
Spearman ρ test for D1, D2, D3, D4, and Q1, Q2, Q3, Q4, Q5.

	D1 – Utility	D2 – Clarity	D3 – Ease of use	D4 – Necessity for more details	Q1 – Easiness	Q2 – Overall utility	Q3 – Intention of future use	Q4 – Completeness	Q5 – Additional Graphics
D1	1	N	N	N	N	N	N	N	N
D2		1	N	N	0.818	N	N	N	N
D3			1	N	0.829	N	0.687	N	N
D4				1	N	N	N	N	N
Q1					1	N	N	N	N
Q2						1	N	N	N
Q3							1	N	N
Q4								1	1.000
Q5									1

Table 22
Comments from experts.

Comment	Is the suggestion taken into account?	Reason/action
1. Guidelines on how to interpret user test results (performed in Step 2: Experimental stage and/or Step 7: Validation stage) could be helpful (1 comment).	No	Recommendations on how the results of the user tests that were performed in Step 7 should influence Step 8 (Refinement stage) could reduce the impact of the experts' subjective judgements. This suggestion has not been taken into account since the results that were obtained in the user tests depend on the type of test that was applied and the design of the test. However, it is not discarded and will be considered when adding guidelines in the future.
2. Specifying more detailed subtasks and how they could be iterated may be helpful (1 comment).	No	Most experts agree that the methodology has an appropriate level of detail and adding more elements could make it more difficult to use. Therefore, the suggestion will not be considered.
3. Highlighting the inputs/outputs (outcomes) of each step could be helpful (1 comment).	Yes	The recommendation has been taken into account and the inputs and outputs of each stage have been clearly highlighted, in both the brief version and the detailed version of the methodology.
4. Examples of how to match usability/UX attributes, domain-related application features, and heuristics could help (1 comment).	Yes	Specifying the degree of a heuristic's coverage (non-covered, partially covered, or covered) could also be helpful. This suggestion has been taken into account. The specification of Step 4 has been complemented by adding clear examples on how to match usability/UX attributes, domain-related application's features, and heuristics.
5. The specification of Step 4 (Correlational stage) may be improved. Specification of the relationship between Step 4 and Step 5 (Selection stage) would probably facilitate understanding of Step 6 (Specification stage) (1 comment).	Yes	This recommendation has been taken into account and the specifications of Step 4 and 5 have been improved.
6. Examples of how two different heuristics could be merged in Step 5 (Selection stage) could probably be of help (1 comment).	No	The comment was made only once. We think that specific examples would only overemphasize the specification.

taken into consideration. In the first validation (first iteration), all stages were refined, and new elements were added to the specification of the methodology. In the second validation (second iteration), changes were made mainly to the specification of Step 4 (Correlational stage).

Based on the results that were obtained from the survey (second validation), we concluded that the experts perceived the methodology to be useful and intend to use it in the future. The methodology's specification is perceived as fair, but the experts think that additional graphics would help. Therefore, we added the BPMN diagrams to facilitate better understanding of the methodology. The experts stated that the stages are explained in sufficient detail and that it is not necessary to add a new stage. In addition, they indicated that presenting both brief and detailed versions of the methodology is useful.

The methodology was recently applied in several case studies to develop new sets of usability/UX heuristics for specific application domains. We conclude that the methodology is effective since it has been used to create new sets of heuristics (a final "product" is obtained). Moreover, it is perceived as useful by the experts who have used it.

The methodology is applicable for developing heuristics for UX-related aspects, such as playability, communicability, and learnability. We also consider the methodology to have great potential in the development of instruments for other quality attributes that require an instrument of heuristic type or guidelines, such as security and adaptability. It has already been applied to develop playability and mixed usability-security heuristics.

In future work, we intend to study how the methodology can be used to develop heuristics for the evaluation of quality attributes other than usability. The methodology's efficiency could be evaluated. However, efficiency criteria should be defined first.

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Appendix A. BPMN diagram for Step 1: Exploratory stage

Fig. 5.

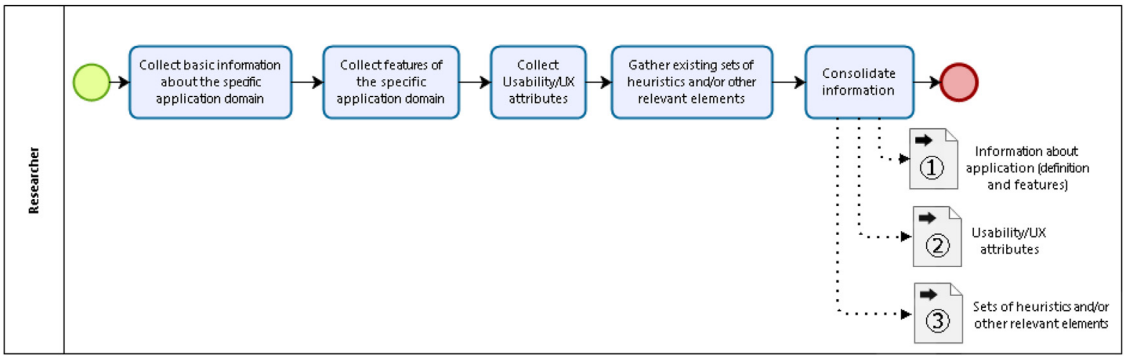

Fig. 5. BPMN diagram – exploratory stage.

Appendix B. BPMN diagram for Step 2: Experimental stage

Fig. 6.

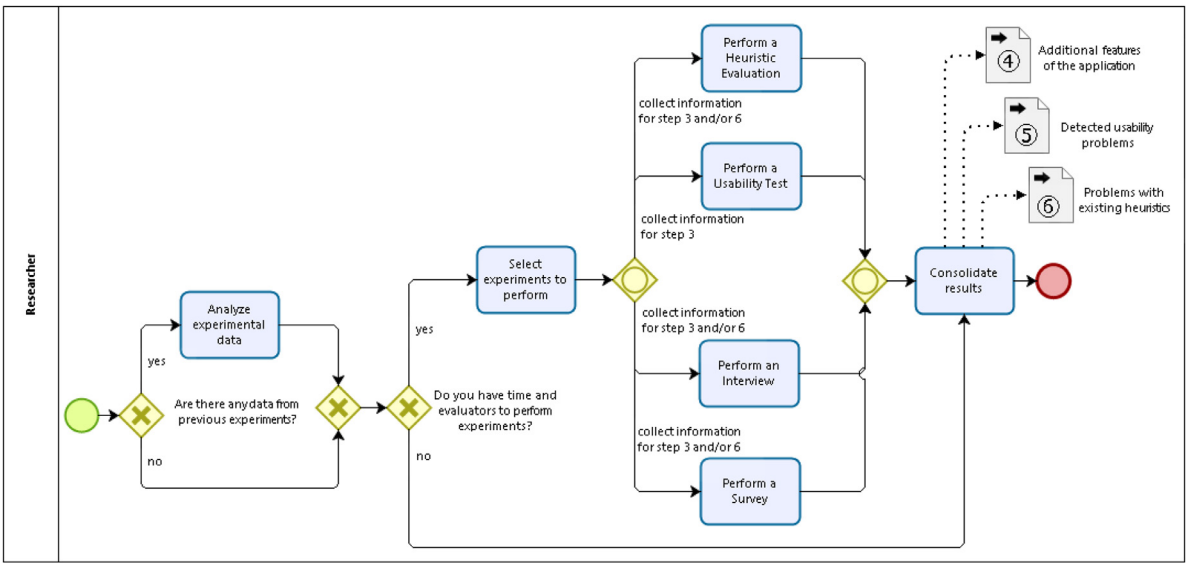

Fig. 6. BPM diagram – experimental stage.

Appendix C. BPMN diagram for Step 3: Descriptive stage

Fig. 7.

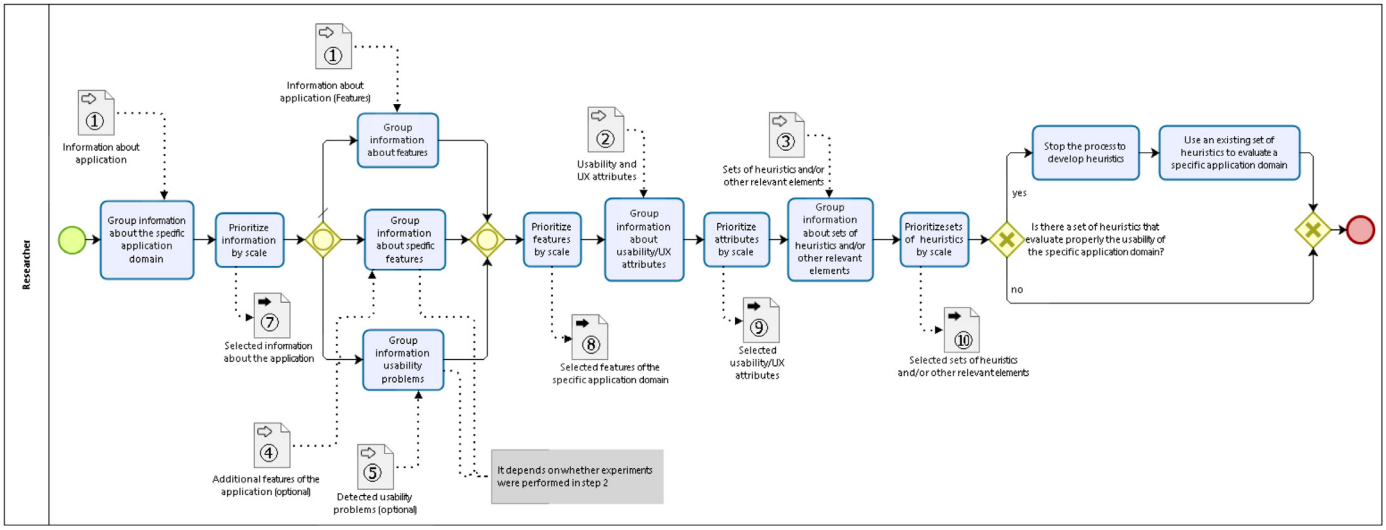

Fig. 7. BPMN diagram – descriptive stage.

Appendix D. BPMN diagram for Step 4: Correlational stage

Fig. 8.

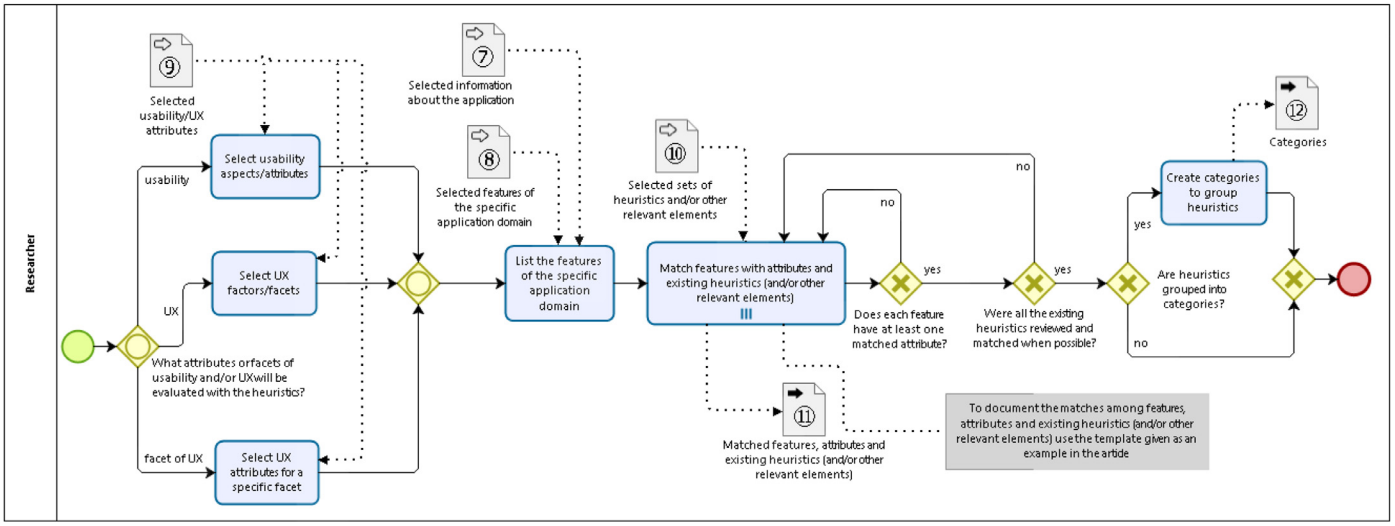

Fig. 8. BPMN diagram – correlational stage.

Appendix E. BPMN diagram for Step 5: Selection stage

Fig. 9.

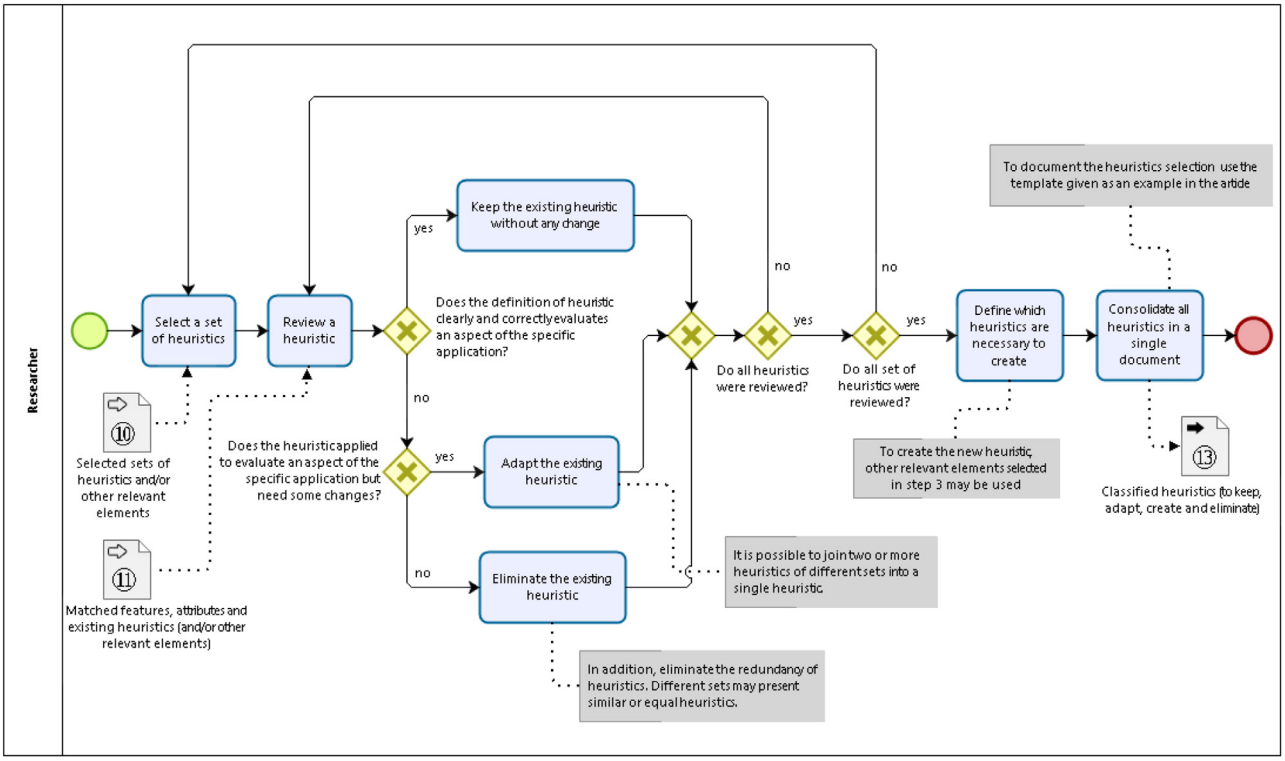

Fig. 9. BPMN diagram – selection stage.

Appendix F. BPMN diagram for Step 6: Specification stage

Fig. 10.

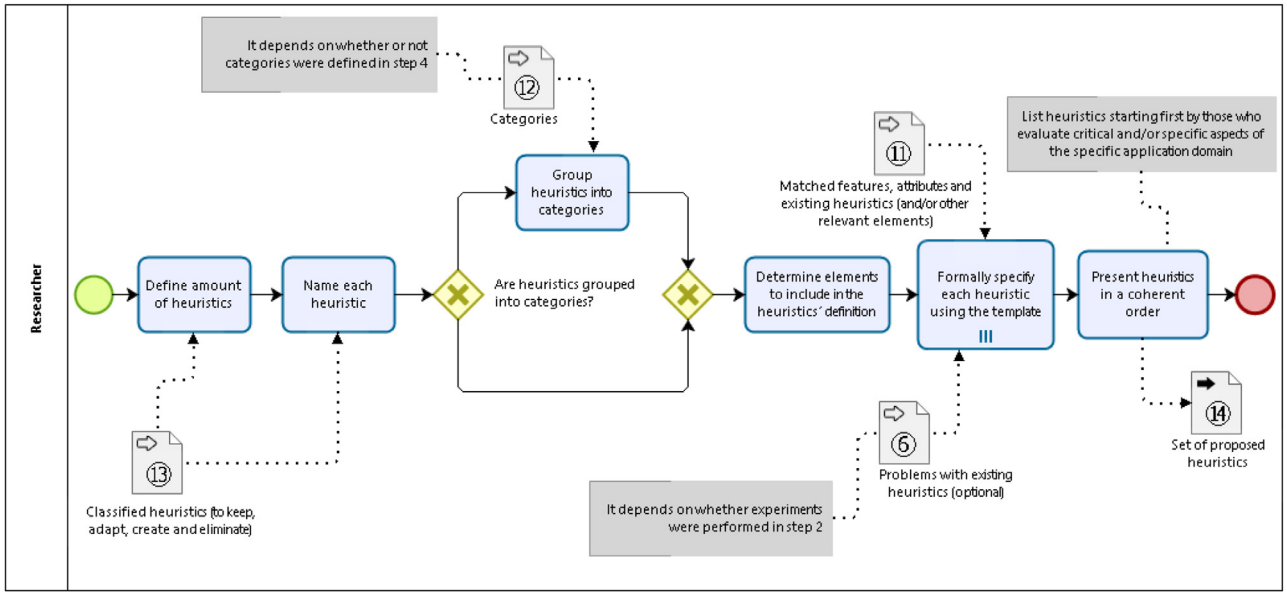

Fig. 10. BPMN diagram – specification stage.

Appendix G. BPMN diagram for Step 7: Validation stage

Fig. 11.

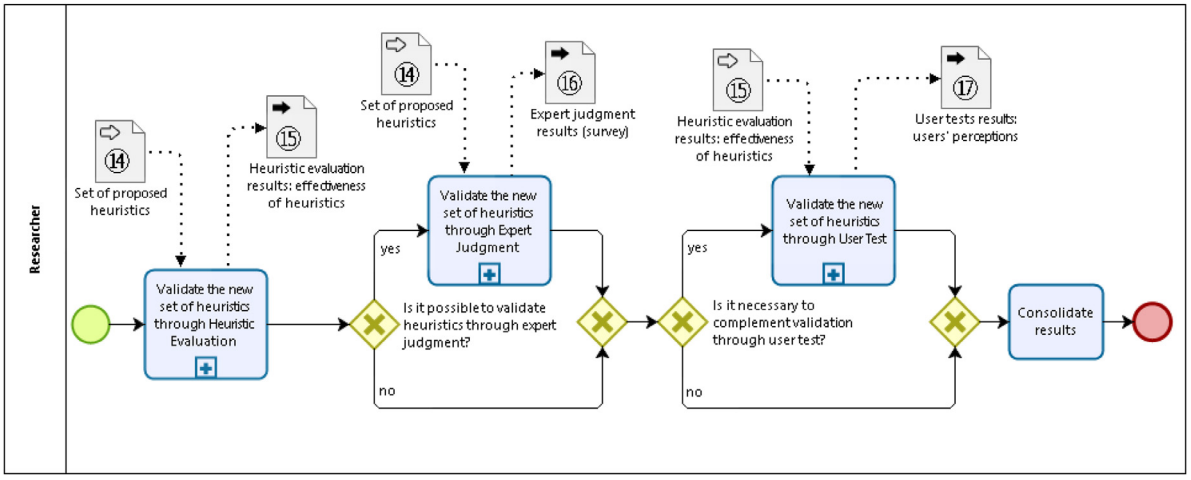

Fig. 11. BPMN diagram – validation stage.

Appendix H. BPMN diagram for validation through heuristic evaluation

Fig. 12.

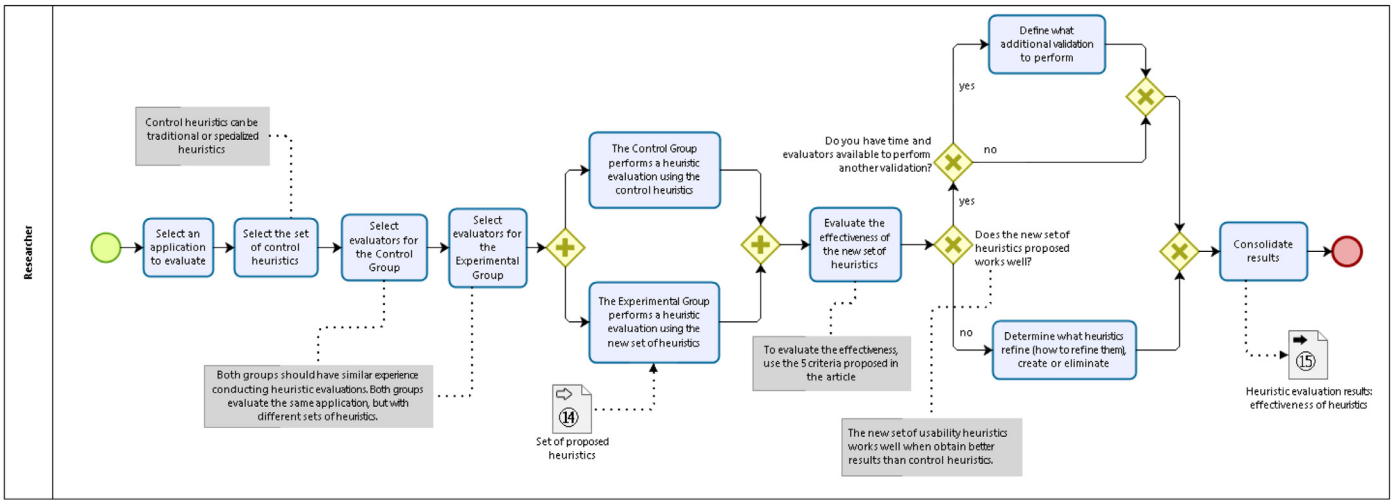

Fig. 12. BPMN diagram – validation through heuristic evaluation.

Appendix I. BPMN diagram for validation through expert judgment

Fig. 13.

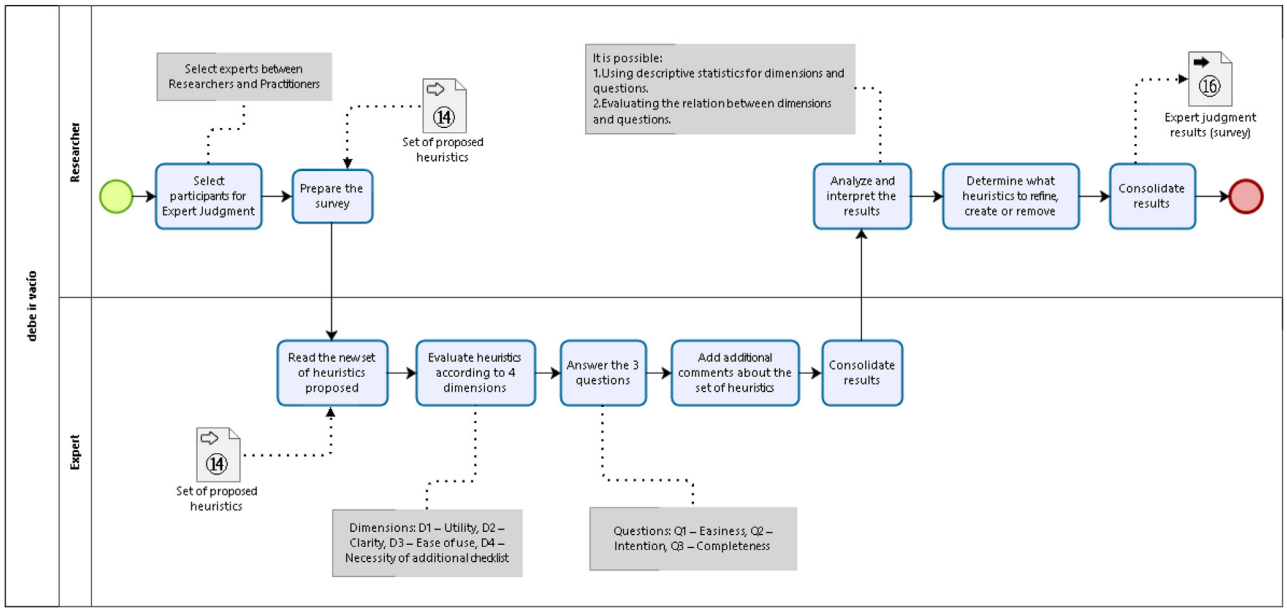

Fig. 13. BPMN diagram – validation through expert judgment.

Appendix J. BPMN diagram for validation through user test

Fig. 14.

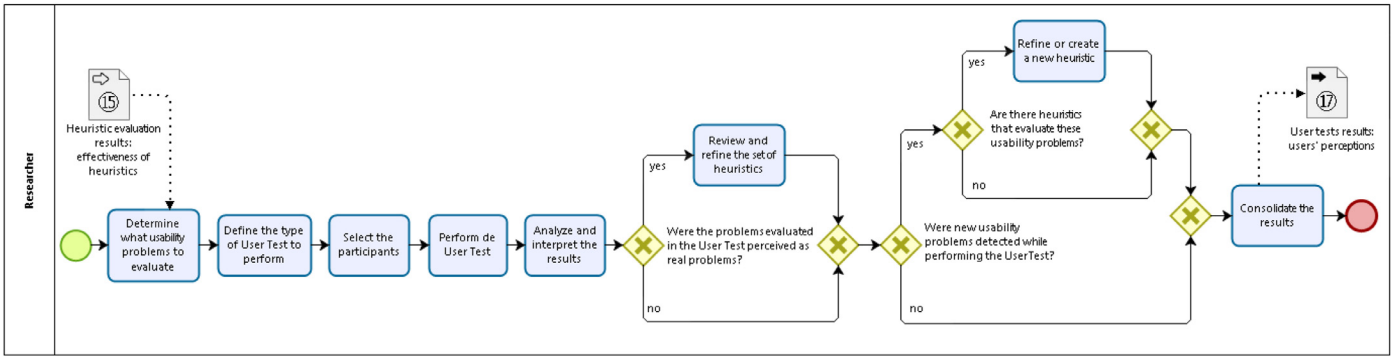

Fig. 14. BPMN diagram – validation through user test.

Appendix K. BPMN diagram for Step 8: Refinement stage

Fig. 15.

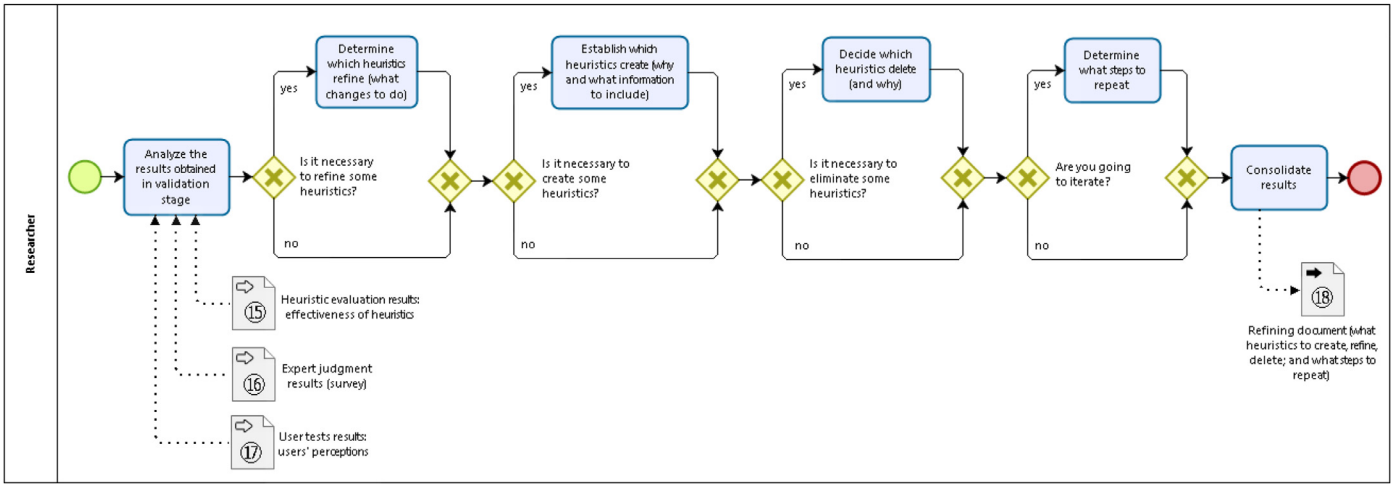

Fig. 15. BPMN diagram – refinement stage.

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