Design Process for Human-Data Interaction: Combining Guidelines with Semio-participatory Techniques

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Abstract: The complexity of analytically reasoning to extract and identify useful knowledge from large masses of data requires that the design of visual analytics tools addresses challenges of facilitating human-data interaction (HDI). Designing data visualisation based on guidelines is fast and low-cost, but does not favour the engagement of people in the process. In this paper, we propose a design process to integrate design based on guidelines with participatory design practices. We investigate, and when necessary, adapt existing practices for each step of our design process. The process was evaluated on a design problem involving a visual analytics tool supporting decisions related to the production strategy in oil reservoirs with the participation of key stakeholders. The generated prototype was tested with adapted participatory evaluation practices. The obtained results indicate participants' satisfaction with the design practices used and detected the fulfilment of users' needs. The design process and the associated practices may serve as a basis for improving the HDI in other contexts.

1 INTRODUCTION

The analysis of large amounts of data has become essential for the success of organisations. This is a complex task that often requires the judgement of domain experts to make the best possible assessment of incomplete and inconsistent information. The construction of tools for this purpose that facilitate human interaction with the data is an important step in achieving the desired results.

Visual analysis (VA), the science of analytical reasoning facilitated by interactive visual interfaces, consists in interactive and iterative dialogue between the human and the computer. The interactive analysis process is a sequence of actions by the user and responses by the computer motivated by analytical questions (Thomas and Cook, 2005) (Turkay et al., 2017). While several VA tools have been developed to support exploration of large amounts of data, they do not yet sufficiently support some complex exploratory analysis scenarios. There is a shortage of support environments where domain specialist and machine work in harmonious interaction for data exploration (Behrisch et al., 2018).

Several studies argue that designing visualisations and VA tools based on guidelines is an important approach to help materializing the knowledge and experience gained by various experts in the field (Shneiderman, 1996); (Scapin and Bastien, 1997); (Freitas et al., 2002); (Amar and Stasko, 2004); (Zuk and Carpendale, 2006); (de Oliveira, 2017). However, in our view, this approach alone does not allow people to participate in the process of building the system.

Recently, the Human-Data Interaction (HDI) area has investigated how people interact with data in a manner analogous to the Human-Computer Interaction (HCI) area in relation to people and computers (Holzinger, 2014); (Knight and Anderson, 2016). HDI studies human manipulation, analysis and meaning creation from voluminous, unstructured and complex datasets (Elmqvist, 2011).

HDI literature have often addressed the broad context of ensuring the privacy and management of data ecosystems (Bach, 2018); the means for people to become aware of the data and the implications of their use and manipulation (Mortier et al., 2014); the capture of personal preferences (Dimara et al., 2018); and the design of mechanisms to support presentation, interpretation and editing by laypersons (Crabtree and Mortier, 2015). Our analysis of the HDI literature

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has indicated that further studies are required to obtain approaches to capture at project time the user's needs in relation to the interactions and the context in which the data will be produced and used (Green et al., 2015); Also, we need to achieve user engagement with data interaction solutions through participation in the design process (Locoro, 2015).

In this context, questions are raised about design approaches. Can the adequate involvement of stakeholders in the VA design process be valuable to improve HDI? Is it feasible to combine the advantages of designing visualisations and VA tools combining guidelines and participatory approaches? In our view, the non-engagement of stakeholders in design can result in a system produced from a single view, which although may be correct, does not describe the reality in a comprehensive way with the vision of all parties potentially affected by its construction.

We claim that the option for the VA interaction design approach based on guidelines should not necessarily exclude the possibility of taking advantage of the participation of people with different profiles. Our approach to HDI investigates ways to enable in-depth interactions with data analysis tools, highlighting the importance of taking into account stakeholders' contributions, the entire data life cycle, and the ability to proactively engage with data in a variety of ways.

In this paper, we propose a design process for HDI in decisions supported by VA that combines the advantages of using participatory practices and guidelines. We consider that the novelty of our study is the combination of the two approaches. The successful realisation of such processes involves a number of elements that need to work in coordination: (i) identifying key stakeholders and ensuring effective participation during design and choice of solutions; ii) search of a set of guidelines to consider as a starting point; iii) selection of relevant guidelines adequate for the context; iv) finding the best way to unravel, explain and facilitate understanding of the chosen guidelines to the various participants; v) definition of practices and adequate flow for the conduction of design activities to ensure they harmoniously flow and produce the desired results.

While developing and refining our approach for design process, we were significantly informed by a series of practices that we have carried out in UNISIM at Center for Petroleum Studies (CEPETRO) that develops methodologies and tools to support an integrated decision analysis in the development and management of petroleum fields (Schiozer et al., 2019). In this study, the design situation involving a VA tool that supports analytical needs for optimisation of oil production strategy provided the opportunity to conduct the necessary design workshops for evaluating our proposal.

The methodology used includes the elicitation and problem clarification meetings based on organisational semiotics artefacts (Liu, 2008). Storyboarding and braindrawing techniques supported the design stage. The results of the design were materialised in a functional prototype and evaluated using conceived practices: participatory HDI design guidelines evaluation and adapted Thinking-aloud. The practices of design and evaluation were performed in an iterative way and a questionnaire was answered by involved participants.

The key contributions of this investigation include: 1) the definition of a design process tailored for HDI design describing the conceived steps to allow future reuse and replication of the dynamics; and 2) the conduction of a case study in a data intensive environment related to oil reservoir management where the process was applied.

2 BACKGROUND AND RELATED WORK

Subsection 2.1 presents the approach to semio-participatory design; Subsection 2.2 introduces design guidelines and evaluation techniques; and Subsection 2.3 reports on a summary of related work.

2.1 Semio-participatory Design

Organisational semiotics helps to get the understanding of the context in which the technical system is inserted and the main forces that direct or indirectly act on the situations (Liu, 2008). It studies the effective use of information in business context and assumes that organised behaviour is effected through the communication and interpretation of signs by people, individually and in groups. Organisational semiotics investigates the organisation at different levels of formalisation - informal, formal, and technical.

The field of participatory design spans a rich diversity of theories, practices, analyses and actions, with the goal of working directly with users and other stakeholders in the design of social systems that are part of human work (Kuhn and Muller, 1993). This approach considers that everyone involved in a design situation is capable of contributing for it.

The semio-participatory approach to interactive system design combines the concepts of organisational semiotics (Liu, 2008) and participatory design (Kuhn and Muller, 1993). It includes shared knowledge and mutual commitment to establish communication during the design process (Baranauskas et al., 2013). Various artefacts are proposed to mediate this communication and facilitate creative and collaborative design engagement into semio-participatory workshops. Artefacts and dynamics are proposed to facilitate the interaction and communication of a group with diversified profile (Baranauskas et al., 2013). The term semio-participatory techniques is used to refer to the application of principles of participatory design with the support of artefacts of organisational semiotics for conducting the workshops.

Semio-participatory workshops are the engine of the model. It moves the design process through the different levels of formalisation throughout the design life cycle. In the beginning of the design process, the conduction of specific participatory practices helps to generate the artefacts called the stakeholder identification diagram (Liu, 2008) and evaluation framework.

Stakeholder identification diagram is a layered structure that facilitates the identification of the involved parties (stakeholders) in a process of new technology conception and introduction. Evaluation framework supports the articulation of problems and the initial search for solutions. It informs about specific issues from stakeholders and ideas or solutions envisaged that have potential impact in the design. The evaluation framework extends the stakeholder identification diagram by considering for each stakeholder issues and solutions to the problems. In our proposal, semio-participatory artefacts is used to guide workshops taking advantage of people's participation since conception and elicitation activities (*cf.* Subsection 3.1).

2.2 Design Conception and Evaluation

Design specialists can compile recommendations acquired in their experience in various projects, and provide designers with the ability to determine the consequences of their design decisions. Design guidelines are recommendations a designer can follow to enhance the interactive properties of the system (Dix et al., 2004). One example of guideline is the information density guideline that suggests "to provide only necessary and immediately usable data; do not overload your views with irrelevant data" (Scapin and Bastien, 1997). Design guidelines vary in their level of abstraction, generality and authority.

In this article, we use the term guideline to talk about design recommendation made by experts and that can be used in the design of other systems in a comprehensive way, without distinguishing the level of generality, abstraction or authority. Guidelines are used as an approach to bring specialists' knowledge to help the identification of points for redesign that favour HDI. Our work combines some specific recommendations collected from HDI literature to a set of guidelines brought from related areas. Our set of heuristics includes, for example, those of Nielsen that refer to general guidelines applicable to all user interfaces (Nielsen, 1994).

The evaluation of systems that make use of visual representations is an extremely complex task. Different from a common user interface, a VA system must be evaluated not only in terms of the interface, but also for the information that it manages. There are several approaches for this kind of evaluation. Some of them are based on expert evaluation whereas others involve final users assessment. The VA evaluation methodology can be subdivided: analytic evaluations and empirical evaluations (Mazza, 2009).

The analytic type of evaluation is carried out by experts who verify whether a certain system is compliant with a series of heuristics or guidelines. Empirical evaluation methods make use of functioning prototypes of systems and involve the final users. In our participatory approach, it is important to count on stakeholders contribution in the evaluation stage. Therefore, in addition to analytical assessments based on guidelines, we conduct empirical assessments.

One of the usability test techniques known as Thinking-aloud (Lewis, 1982) consists in asking users to think aloud about what they are doing while using the system. The expectation is that the thoughts show how user interprets each interface item.

Another set of evaluation techniques relies on asking the user about the interface. Query techniques can be useful in eliciting detail about user's view of a system. They can be explored in evaluation with the advantage of getting users' viewpoint directly and may reveal issues that have not been considered by designers. Interviews and questionnaires are the main types of this technique (Dix et al., 2004).

The techniques mentioned here are not enough to support our study. Therefore, we propose adaptations to the evaluation practices to engage stakeholders at the same time that we aggregate the knowledge and experience acquired by experts through the use of guidelines.

2.3 Related Work

The incontestable alternatives to our proposal are purely participatory processes or purely based on guidelines, as discussed in Section 1. This Section improves the literature analysis by discussing similar study alternatives and their limitations for the application in our context.

Ceneda *et al.* (Ceneda et al., 2017) proposed a process to favour interaction in the VA which seeks solutions to support users during data analysis. Their work concerns the user guidance aspects of a generic visualisation environment to progress in their data analysis. Their study does not focus in the interaction design of VA tools.

The proposal for design data practices presented by Churchill (Churchill, 2016) attempts to demystify the "genius designer" whose instincts and intuition lead to great design decisions. The work states the need of taking a proactive and critical stance to design, develop, or evaluate products that incorporate capture, storage and data analysis. It lists some practical things that can be done, but does not propose a design process for tools that deal with data.

Leman *et al.* (Leman et al., 2013) studied typical data visualisations that results from linear pipelines that start by characterising data and end by displaying the data. The proposal goal was to provide users with natural means to adjust the displays to support good HDI. This method supports a dynamic process for defining visualisations in which users learn from visualisations and the visualisations adjust to the expert's judgement. This proposal differs from ours mainly because it is a method for the execution time and not a process for design.

Buchdid *et al.* (Buchdid et al., 2014) described an approach for design combining participatory practices with Interactive Digital Television patterns using the principles of organisational semiotics. Their context dealt with a few patterns. It was possible to explain all the patterns in advance and train the participants on Interactive Digital Television patterns before beginning the design workshops. Our proposal distinguishes itself from this mostly because participatory guidelines evaluation was carried after the first prototype generation as a way to incentive creative solutions.

A review of Nielsen's heuristic evaluation method based on participatory concerns including users (work-domain experts) as inspectors was proposed by Muller *et al.* (Muller et al., 1998). They extended the original Nielsen's heuristic set with several process-oriented heuristics. Their evaluation method can help to guide iterative designs process. This technique is similar to one of the practices proposed in our work, but it is focused in a specific Nielsen's heuristics set extension and does not address the issue of HDI.

The online community was target of a study that combined participatory methods for design and development with heuristic evaluation applied iteratively (Preece et al., 2004). First, a specific set of guidelines was developed, extending the Nielsen's heuristics and adding a specific set of sociability heuristic. To refine the set of sociability guidelines, it was turned into a questionnaire and open questions that was iteratively tested with online communities. The study of the feedback allowed the elaboration of new items for the test and the refinement of the heuristics.

The studies conducted by Muller *et al.* (Muller et al., 1998) and Preece *et al.* (Preece et al., 2004) conceived practices of evaluation by guidelines combined with participatory methods. However, these studies did not involve VA and did not focus on HDI nor propose a process. These facts highlight the innovation of our proposal for design process which combines participatory design and HDI guidelines.

3 INTEGRATING HDI GUIDELINES AND SEMIO-PARTICIPATORY PRACTICES

This section presents our proposal for a new design process for HDI that combines guidelines with semio-participatory practices. Our proposed process includes several activities. Figure 1 presents the proposed flow that drives the activities.

3.1 Problem Clarification Activities

Initially, it is necessary to identify the stakeholders, understand their concepts, terms and values in the design problem (Liu, 2008). Stakeholder identification diagram is the supporting artefact for this stage in semio-participatory workshops. It helps thinking beyond traditional participants and involving the ones who may direct or indirectly influence or be influenced by the solution under design (Baranauskas et al., 2013).

From the overview obtained with stakeholder identification diagram, it is important to know the problems and issues as well as the ideas and solutions related to each stakeholder. They can have different perspectives about the subject. The evaluation framework is the artefact used to support this part of the process (Baranauskas et al., 2013).

Several types of activities can be held to allow the delimitation of scope for the design project. We propose to use the semio-participatory artefacts to understand the subject during the elicitation activities. The techniques can be presentations, group dynamics, interviews, document analysis or others (*cf.* item A of Figure 1).

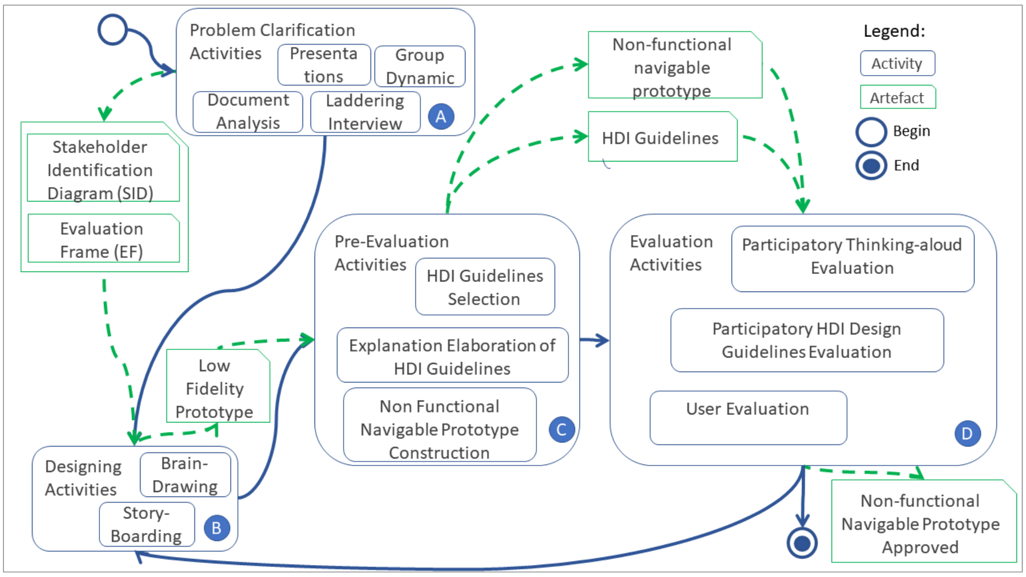

Figure 1: Process for design HDI combining guidelines with participatory design approaches.

In this context, Laddering interview, a special type of interview approach that can be carried out with users to understand the participants' views and personal values is specially useful (Bourne and Jenkins, 2005). Discussion begins with concrete aspects and evolves to more abstract level and the topic of conversation evolves naturally.

3.2 Design Activities

In some situations the design involves a game of forces, where some stakeholders may exert a disproportionate influence on the project. In the participatory design philosophy, this situation must be avoided through mechanisms that seek to balance the forces. Participants of all hierarchical levels should give their contributions during participatory design workshops. Techniques such as storyboarding and braindrawing (*cf.* item B of Figure 1) facilitate the engagement.

Storyboarding. An interaction scenario must be properly defined and tasks performed in the scope of the activity should be well delineated. This helps in the understanding of the scenario by all those involved in the design. The functionality under design and the various steps involved in it need to be well described. Sometimes a verbal or written description is enough. However, if the problem involves participants with different profiles, it may be necessary to adopt visual techniques to promote a complete understanding. In our approach, stakeholders might contribute in the storyboarding creation.

A description based on storyboarding can help in the pre-visualisation of a digital interface that might support some task. It uses a sequence of stages where each stage shows a moment in time, *e.g.*, an interface state. It visually tells a story. It is useful for participants to interpret how each interface proposal fits into the design problem. After reaching a consensus about the flow, the solution supporting each interface state can be designed.

Braindrawing. It is a technique used to materialise ideas and proposals into interface low-fidelity prototypes for digital applications. In our process, each interface state identified in the storyboard is the target of a braindrawing section.

In this step, all participants are arranged in a circle. Each participant draws its initial idea for the interface that would support the defined task using a sheet of paper and pen. After a predetermined short period of time, the drawing is passed to the next participant who completes it. This step is repeated until each participant received his/her original drawing back. Then, each participant presents his proposal to the others. The group must agree on a candidate solution to be adopted. The solution may involve common elements of several proposals.

3.3 Pre-evaluation Activities

In our proposal, the group creates during design activities a low fidelity prototype without design guidelines orientation. The guidelines are introduced in the evaluation phase. The evaluation of the prototype requires some preparation activities (*cf.* item C of Figure 1):

Construction of a Non Functional Navigable Prototype. It is important that the prototype be navigable to facilitate the evaluation of HDI. Based on the low fidelity prototypes and the accorded storyboarding, a designer can propose a navigable prototype.

Selection of HDI Guidelines and Elaboration of Explanation for HDI Guidelines. Designers should define which sets of guidelines are relevant to be used. Given the nature and complexity of the problem of facilitating the HDI for VA application, we consider it is important to aggregate guidelines of the VA, HCI and HDI area. We draw upon previous studies (de Oliveira, 2017) with a compiled set of VA and HCI guidelines and heuristics (Shneiderman, 1996), (Scapin and Bastien, 1997), (Freitas et al., 2002), (Amar and Stasko, 2004), (Zuk and Carpendale, 2006). In this work, we call the set that resulted from this junction as the initial set of HDI design guidelines. If there are any set of guidelines for the application domain or standards used by the target organisation, they should also be included.

Afterwards, the designers should select which guidelines from the initial set are related to the scope of the prototype and that matters in the context. One way to facilitate the selection is grouping the guidelines by subject in clusters. One set could aggregate, *e.g.*,, all guidelines related to the amount of information showed to the user. It is then necessary to find ways to unravel, explain and facilitate understanding of those chosen guidelines to allow participants comprehending them and to decide on their use. Using examples, even if they are from different contexts, are a good way to explain the guidelines.

3.4 Evaluation Activities

The navigable prototype and the selected guidelines support the evaluation activities and help decisions to improve and refine the prototype. We propose a participatory approach for the activities of evaluation phase. All identified points in the evaluation phase needs to be organised in a priority order to be treated in a redesign cycle.

We need to verify to which extent users think the prototype might help them accomplishing their tasks; and how the prototype can be improved. For support this stage, we propose two new participatory evaluation practices: Participatory Thinking-aloud Evaluation and Participatory HDI Design Guidelines Evaluation. These new practices should be associated to an User Evaluation (*cf.* item D of Figure 1).

Participatory Thinking-aloud Evaluation. Our proposed dynamics was adapted from the original Thinking-Aloud method defined in (Lewis, 1982) and the adaptation presented in (Buchdid et al., 2014). A participant is invited to interact with the navigable prototype to complete an use case, conducting a predefined task, previously explained to the group. In our proposal, during the interaction, the whole group is stimulated to report their thoughts and impressions about the prototype. All participants in the workshop speak aloud while one participant interacts with the prototype. This activity allows knowing the impression that a prototype caused.

Participatory HDI Design Guidelines Evaluation. We claim that the participants should, in the beginning of the design process, propose alternatives freely before worrying about guidelines. In this sense, they do not stop thinking in creative ways to solve the problem and are not skewed in attending a guideline. Thus, in each round of the process the guidelines usage starts after the elaboration and consensus of the design activities.

This activity should be leaded by a designer. For each guideline, participants are introduced to the recommendation of design with an explanation and examples of applications, previously prepared.

After the explanation, participants should discuss the application, the impacts as well the advantages and disadvantages of adoption. They need to decide if the guideline are going to be adopted. Finally, a subset of the discussed guidelines potentially useful and the associated ideas for redesign can be generated by this activity.

We recommend to first carry out the Thinking-aloud and then the HDI design guidelines evaluation so participants have in mind the status of the prototype to relate it with the guidelines. Based on the issues found during the participatory evaluation activities, participants elaborate a list of problems and suggestions for improving the application in a redesign phase.

At this point, the team has the opportunity to decide if they are going to make a redesign activity to adjust the prototype to issues identified. If the group decision is to change the prototype, it may be necessary to return to the storyboarding and braindrawing activities. This cycle can be repeated more than once until participants feel that the prototype design is appropriate for their needs.

User Evaluation. When the design of the prototype is mature, an user evaluation based in the Query Technique (Dix et al., 2004) with all participants is conducted asking the participants about the results directly. It is applied by interview or questionnaire.

4 CASE STUDY

One challenge being addressed by UNISIM consists in the investigation of technologies for deterministic optimal production strategy selection in oil fields (Schiozer et al., 2019). This process involves a lot of efforts in analysis of voluminous data. SEPIA is a VA software tool developed to facilitate this process.

One step for optimisation of the production strategy requires the performance of many simulations, with some variations among them. After some simulations, it is necessary to make comparisons to verify the differences that resulted from the changes made from one simulation to another. SEPIA does not have specific functionalities to support this scenario. In this case study, we address how to allow the evolution of SEPIA with HDI design for comparisons among different oil production strategies. Our proposed design process was applied to this scenario.

The activities of this study were conducted from June to December, 2018, and involved 2 Computer Science researchers and 6-8 participants playing different roles at UNISIM One of the Computer Science researcher played the role of designer throughout the process. The application required 7 meetings and workshops of 3 hours each on average. Thus, the whole process was conducted in approximately 21 hours of meeting with 6 participants on average. In addition, a similar effort was made to prepare the presentations and practices for each meeting. We present the results for each step in the following.

4.1 Results of Design Problem Clarification Activities

The process began with stakeholders identification followed by issues and requirements elicitation.

Stakeholders, Values and Interest. There are many stakeholders potentially involved with SEPIA tool and they were detected by the stakeholder identification diagram elaborated in the participatory practices. The initial group of stakeholders was distributed in the stakeholder identification diagram inner layers. For example, "Developers" was inserted in the operation layer of stakeholder identification diagram; "Designers" was inserted between the operation and contribution layers. UNISIM and the development project manager figured in the contribution layer because they are responsible for the production of the tool. In the source layer are the engineers and researchers which are very important stakeholders because they are real users of SEPIA tool.

The presentation of the initial stakeholder diagram helped the detection of others interested indirectly connected with SEPIA. For example, in market layer there is CMG[1], a reservoir simulation software developer, and other tools vendors. In the community layer we inserted the Brazilian regulation agency for the activities that integrate the oil and natural gas and biofuel industries in Brazil, the ANP[2].

After this activity, the end users with the engineering and research profile began to participate in the workshops. They participate very actively during the clarification and design workshops.

Issues and Requirements. In the elicitation phase, there were presentations related to underlying domain concepts, so the designers and developers could begin understanding the complex domain of strategies for petroleum exploration. To deepen this understanding, we conducted 4 individual interviews with an average duration of one and a half hour based in laddering techniques with the SEPIA users.

The users were encouraged to speak about their daily activities, their issues and problems and solutions they see to the problems. The results of the interviews revealed that one issue was the execution of several attempts to optimise the strategies and the comparison of the results. However, time, volume of data and number of files involved in these attempts turn difficult the comparisons among obtained results from simulations. One user, *e.g.*, made several simulations by slightly varying the position of a specific well that was part of a particular production strategy. She used bar chart views to compare strategy results with the various well positions in relation to return of investment and oil volume produced. The support for the comparison between strategies was chosen as the central requirement to be addressed in the first version of the prototype and to validate the execution of the process proposed in this article.

4.2 Results of Design Activities

The issues, problems, ideas and solutions identified during design problem clarification activities were the source for the design.

The Storyboarding. The first participatory design activity was conducted in a meeting with the goal of consolidating the needs reported by users in the interviews. They needed to agree on the scope for the next activities.

A Storyboarding was conceived as a state transition diagram and illustrated with visual interface prototypes to support the discussion of the execution flow

[1]https://www.cmgl.ca/software
[2]http://www.anp.gov.br

of two actual use cases of comparisons. The flow presented by the storyboard had to be changed as the design activities were progressing. The technique was very useful during all the process to build an agreement about the execution flow under discussion. Figure 2 shows the flow in the storyboard.

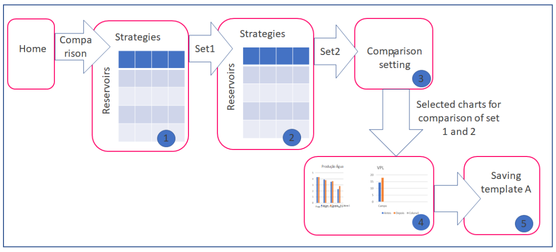

Figure 2: Storyboard showing the execution flow agreed in participatory design activity.

Braindrawing. After getting consensus for the first version of the storyboard, it was possible to identify the goal of each interface involved in the process. Braindrawing sections were guided by the flow and states defined in the Storyboarding practice. We conducted one Braindrawing section for each relevant state identified in the storyboard.

In the Braindrawing sections, each participant had one minute to draw the screen for achieve the desired goal following the steps explained in Subsection 3.2. On average, the Braindrawings were elaborated by six participants and the drawing phase took no more than 30 minutes. This procedure generated several alternatives ideas for each interface. Each idea was presented by who initially proposed the design solution. After the team discussed the ideas, a consolidated interface screen was defined. It took another 30 to 60 minutes. In general, the consolidated drawing joined ideas from several participants.

4.3 Results of Pre-evaluation Activities

After the initial design and before the evaluation phase, preparation activities were necessary to facilitate the work of the entire group. These activities were performed by the designer.

Prototype Construction. The Braindrawing workshops results, low-fidelity paper prototypes, were transformed into navigable medium-fidelity prototypes. A navigable prototype was very useful during the Thinking-aloud activities and helped to raise a lot of issues, questions and suggestions.

The Guidelines Selection and Explanation. The designer was responsible for selecting the guidelines that were most related with the prototype scope and for explaining the guidelines to the group. The previously compiled set on which we based was useful because it ranked the recomendations found in influential contributions in the VA and HCI areas by creating clusters of guidelines (de Oliveira, 2017). The clusters grouped the guidelines by subject and facilitated the selection of the subset that matter to our scope.

We organised an additional cluster with HDI guidelines found in literature. Examples of guidelines found in HDI and used in this study are: i) "Consider all stages of the data life-cycle and the relevant stakeholders" (Hornung et al., 2015); ii) "Consider values in the design and implementation of analytics considering how technologies can materialise values, and their interpretive flexibility." (Knight and Anderson, 2016); and iii) "Provide visual or textual indicators aspects of search like relevance, usability and quality on the interface, backed up by automatically computed metrics or user-generated reviews and annotations." (Koesten et al., 2017).

There are not any known set of guidelines for visualisations in the oil production domain, to our knowledge. In UNISIM there is a colour standard to differentiate the representation of activities according to the stage of the methodology in which it is executed. One colour is used for activities related to reservoir modelling and construction, another for reduction of scenarios (data assimilation) a third colour represents long-term production optimization (prediction) and a four colour represents sort-term production optimization activities for the future. Then, this specific guidelines was included in the set.

4.4 Results Evaluation Activities

The Participatory HDI Design Guidelines Evaluation. This practice, facilitated by one designer, involved all design workshop participants. The selected guidelines were explained to the group so they can decide whether changes suggested by the guidelines could benefit the prototype. In general, each selected guideline was explained and discussed at a time.

During the consolidation of the proposal for the comparison visualisation interface (*cf.* item 4 of Figure 2), the participants liked an idea different from the approach currently used in SEPIA. The participants liked the new approach, but they were uncomfortable with the paradigm shift at the first moment. It was considered that the evaluation based on HDI guidelines could help to support the choice. In particular, the following guidelines were discussed:

- "Shneiderman mantra": *overview first, zoom and filter, than details on demand.*

- "Information density" (Scapin and Bastien, 1997): provide only immediately usable data; do not overload views with irrelevant data.
- "Filter the uninteresting" (Shneiderman, 1996): allow users to control display content and quickly focus on interests by eliminating unwanted items.
- Cycle of data (Hornung et al., 2015): "Consider all stages of the data lifecycle".

Currently in SEPIA, in situations similar to those under design, all graphs of all the wells would be generated and displayed at the same time giving an overview of the data. However, it may overload the user view with irrelevant data and make it difficult the selection of view with data of the desired well. Considering the new approach designed, only one well graphic would be shown in each frame with a widget control to quickly focus on the interesting well and eliminating others wells graphics. This approach seems to reduce the information density, but eliminates the overview of data that was familiar to users.

With the presentation of the guidelines, it was considered that the overview guaranteed by the more traditional approach did not bring relevant information to the analysis at this moment. Considering all the data life-cycle, the overview was necessary only at the beginning of the process. In addition, users would not like to have to undertake complex activities when the complexity is not required by the task at hand. Supported by the analyses of the guidelines in the context of the interface under discussion, participants were able to approve the innovative design option more comfortably.

Participatory Thinking-aloud Evaluation Activities. The Thinking-aloud process was undertake in groups of five to six people. In the first section, only the designer handled the prototype, because other participants did not want to do it. In the second time, the prototype was more familiar to them, and one of the participants volunteered to navigate in the prototype.

All the participants deeply contributed, which made the sections long. They lasted one and a half hour on average. They were very productive to refine the ideas for the redesign of the prototype.

Sometimes the expressed thoughts led to modifications with low impact like changing the location of an interface component, *e.g.*, the action buttons positions. But, it was also identified an opportunity of improvement concerning the interaction approach that would demand a high impact change in the flow of execution.

User Evaluation Activities Results. In the final stage of the process, the participants were invited to answer a questionnaire and one open question evaluating the resulting prototype from previous activities.

The evaluation used a Likert scale from 0 to 3 in which the respondents specified their level of agreement with the adequacy of the generated prototype. Notes 2 and 3 were considered positive. Five people answered the questionnaire (all of them had participated in the design and evaluation activities).

The questions attempted to identify users' assessment of the prototype in general, and specifically regarding the adequacy of interfaces design, interaction flow and meeting general users' needs. Table 1 presents results for each question, where Aver. Grade is the average grade for all respondents, %Positive represents the percentage of grades greater than or equal to 2 and %Max. Grade is the percentage of grades equals to 3. The overall evaluation was considered positive for 100.0% of the participants and 66.7% of them rated at the maximum grade. The adequacy of the execution flow was the only item that did not get 100% of positive opinion. The adequacy of consolidated design to meet the stakeholders' needs was rated with the highest grades.

4.5 Participants' Assessment of the Process

After the design and evaluation activities, all participants were invited to evaluate the process used through a questionnaire and open question. The scale and the criteria to consider a positive opinion was the same used for the prototype evaluation. Five participants answered the questionnaire.

Table 2 presents the obtained results. The process overall evaluation was considered positive for 100.0% of the participants and 33.3% rated them at maximum grade. For the questions about specific issues regarding the various activities of the process, the item with the worst grade was about the time involved, having only 40% of positive opinion and 0% of maximum grade. The best aspect considered by the participants was the adequacy of practices used for the objectives with 100% of positive opinion and maximum grade.

5 DISCUSSION

We proposed to combine the advantages of using guidelines and participatory practices in a design process for HDI in decisions supported by the VA. The participatory evaluation practices helped us to understand if the generated prototype made sense for stakeholders. We verified to what extent users think the

Table 1: Prototype Evaluation.

Question	Aver. Grade	%Positive	% Max. Grade
What is your overall evaluation of the results generated by the workshops	2.5	100.0	66.7
Is the consolidated design suitable for the proposed screens?	2.5	100.0	66.7
Is the flow of the proposed interaction suitable for the comparison functionality?	2.5	75.0	66.7
Does the comparison functionality as prototyped suit your needs as a user?	2.63	100.0	66.7
Does the comparison functionality as prototyped suit meet the needs of the majority of users?	2.63	100.0	66.7

Table 2: Process Evaluation.

Question	Aver. Grade	%Positive	% Max. Grade
What is your overall evaluation of workshops you attended?	2.25	100.0	33.3
What is your opinion about the time involved in the workshops?	1.4	40.0	0.0
Did you feel comfortable expressing your opinions?	2.8	100.0	75.0
Were the practices used in the workshops adequate for the objectives?	3.0	100.0	100.0
Did the activities allow the reconciliation of different points of view?	2.4	100.0	25.0
Did the meetings allow the creation of shared understanding of the problem addressed?	2.2	80.0	25.0
Did braindraw's activity help bring about new design solutions?	2.6	100.0	75.0
Was the navigable prototype useful for understanding the solutions being discussed?	2.8	100.0	75.0
Was Thinking-aloud useful for prototype evaluation?	2.8	100.0	75.0
Was the presentation of design guidelines sufficient to understand the recommendation?	2.0	80.0	25.0

prototype might help them and in what points the prototype can be improved. The evaluation practices also sought to understand relevant aspects about the suitability of the process.

Our achieved results indicate that both the proposed process and the product generated by it, the prototype, had good acceptance. However, some points of improvement were evidenced by users feedbacks. Two main issues found were the duration of the meetings and the guidelines understanding.

One of the challenges to ensuring the effective participation of key stakeholders is the time and effort required to participate during the process as a whole. In our study case, many meetings were necessary for understanding, delimiting the scope, design and approve the solution. The process proved to be somewhat onerous in relation to the number of meetings and their duration. The time spent in meetings and workshops, as detailed in Section 4, was perceived by the participants as taking much time.

It was not feasible to ensure the participation of all experts over a very long period of time. The strategy used to minimise the effort required was to alternate meetings with and without final users, or at a high level with focus on the domain understanding and low level with focus on practical aspects of the tool. After the meetings with specific focus, we gathered all stakeholders to hold a hands-on workshop.

The time involved in the activities should be considered to enable further applicability of the process. Some participants suggested ways to speed up the meeting with stricter control of the meeting agenda. However, care must be taken that stricter control does not inhibit the participation and creativity of all.

Regarding the moment of the guidelines application, both the use of guidelines at design time and at the time of evaluation have their advantages and challenges. In the scenario of this investigation, if the guidelines were used in the beginning of the design, it would be difficult and time consuming to train the participants in all the guidelines. On the other hand, the guidelines-based evaluation conducted by design experts would require a lot of effort to train them in the application domain due to the complexity of the subject. Teaching the design guidelines to the participants was challenging, but the training of design specialists on the subjects of oil production strategies domain would be even harder.

Therefore, it would not be possible to include several design specialists in the evaluation process. We involved only two design specialists and prioritised the participation of users in the evaluation phase. More specifically, we found that conducting a participatory evaluation based on guidelines after the design phase allowed the reduction of the number of relevant guidelines that needed to be addressed in the training. It proved to be advantageous in terms of training effort and the process was viable with good results.

This investigation demonstrated that the adequate involvement of stakeholders in the VA design process is valuable to improve HDI. In addition, our findings revealed the feasibility of combining the advantages of designing visualisations and VA tools based on guidelines and participatory approaches.

As future steps, we plan to identify well-delineated scopes that can be easily explained to design specialists and conducting a guideline evaluation involving several design specialists. In addition, we seek to investigate other ways to facilitate the understanding of the guidelines. We intend to combine examples from other contexts and examples adopted in other visualisation tools for the same domain. After discussing these examples, we can devise activities to practice exercises with the use of guidelines in fake problems.

The ease or difficulty to obtain consensus in the decisions is an interesting point to consider in a participatory process. In a context in which a single participant suggested altering one proposal made individually by another, consensus probably would be not so easy. But in this process, both the initial ideas and the proposals for change in the prototype came from several different participants and the ideas were discussed as soon as they arose. The acceptance of the changes was facilitated and solutions were adopted in consensus by the whole group.

Finally, during the participatory practices, the constructive nature of the process allowed to observe how shared understanding about the problem domain was obtained, different viewpoints were conciliated, different proposals were consolidated, and the application was created. The discussions, , were very fruitful and led to the materialisation of the proposed solutions.

So we found that, although sometimes costly in the design time, it is achievable to combine the advantages of designing visualisations and VA tools based on guidelines and of the participatory approaches. In addition, stakeholder involvement in the VA design process can help improve HDI. Advances in HDI design reduce the likelihood of rework after solution development, thus offsetting the additional efforts made with participatory practices.

6 CONCLUSION

The design of HDI-oriented software applications involving the visualisation of huge volumes of data to guide sensitive decisions is still a open research problem. This paper proposed a design process to improve HDI in VA that combines the advantages of both data visualisation guidelines and participatory practices. We applied it in a case study for VA tool used in the decision on the oil production strategy. Our obtained results indicated users positive evaluation of the prototype generated by the process. Participants demonstrated satisfaction with the practices used and comfort to express their ideas. Our research findings revealed that the combination of design approaches may allow better decisions to be made through VA of voluminous data. Our proposal presents good potential for applications in the design of VA solutions involving HDI in domains of high complexity. In future work, we plan to address open challenges involving the extension of the process to allow refining the guidelines set from users' answers to open questions. We plan to investigate how to measure the HDI improvement in addition to test the process in other HDI domains.

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