Playing the Role of Co-designers on Mobile PWAs: An Investigation of End-Users Interaction

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Abstract: Progressive Web App (PWA) is a new approach that combines technology resources of both web and native apps. End-User Development (EUD) is an approach from which end-users participate actively in a system's design process. PWAs are a recent technology and the impacts of associating EUD and PWAs have been little exploited. To cover this gap, we proposed the PWA-EU approach in previous work. In this paper, we present an investigation about end-users interactions when they act as co-designers on PWAs. We built a mobile app based on the PWA-EU approach and conducted a study with 18 participants with eight acting as co-designers of the app, and ten interacting as non-designers. We carried out a qualitative analysis from the participants' interaction focusing on the breakdowns communication and user experience (UX) of the participants. Our gathered evidence points out that even acting as co-designers participants still have communication breakdowns. Moreover, those who acted as co-designs had a more satisfying experience than those who did not.

1 INTRODUCTION

The use of mobile devices to access the internet is more popular around the globe than the use of desktops (Comscore, 2017). Mobile devices are considered part of individuals' daily activities which include access to different information systems such as online banking, e-learning systems and so on (Casadei et al., 2017). Designers and developers must consider browsers and device limitations when working with mobile or web apps. With those limitations in mind, the need for adapting interfaces on different screen sizes, resources, and dimensions becomes relevant (Bueno and Zaina, 2017; Gullà et al., 2015).

Responsive Web Design (RWD) arose as a popular solution to user interface (UI) adaptation for mobile web apps (Marcotte, 2011). From the RWD approach, the interface adaptation runs automatically by considering the device screen width, orientation, and platform by CSS media queries (Bryant and Jones, 2012).

Progressive Web App (PWA) is proposed by Google in 2015. It combines both web and native apps technology resources. Initially, PWAs are presented as RWD mobile apps which after continuous user interactions, progressively become more complete and similar to the natives (Petele, 2016). This feature provides an adaptive nature to PWAs since their UIs get more complete according to the growth of user interactions.

Considering end-users side, end-user development (EUD) focuses on allowing users who are not primarily interested in software to create, modify and extend a system according to their needs. Meta-design is a EUD approach in which the end-user can participate actively in application development and is not restricted to its use (Fischer, 2009).

The adaptive nature of PWAs brings great potential to be associated with meta-design since both approaches allow apps to become more complete while the user builds a relationship with it. Due to that, the aim of this paper was to investigate the issues and the UX of end-users when they act as co-designers on PWAs. We called co-designers individuals that can change the user interface design on the app runtime. To conduct our investigation, we defined two research questions (RQs): *(i) Which communication breakdowns come up when users play the role of co-designers in a PWA?"* and *(ii) How are users' perception of UX when interacting as co-designers?*.

The traditional PWA approach was not prepared to allow end-users to make their own preferences option.

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Taking into account this limitation we proposed the PWA-EU approach (Cardieri and Zaina, 2019). Our proposal is an extension of the traditional PWA architecture that includes meta-design in a way that users can include their preferences to adapt interfaces on run-time. Another motivation for the PWA-EU proposal is the small number of studies on PWAs, especially when we consider the user perspective. Considering the aim of this paper, we built a mobile app based on the PWA-EU approach to be used in our study. We conducted a study with 18 participants, in which eight acted as co-designers of the app, which means they selected their preferences in order to customize the PWA's appearance, and ten interacted as non-designers. We carried out a qualitative analysis of recordings collected from the participants' interaction. We also analyzed the participants' perceptions of their experience with the approach.

The main contribution of our work is how the communication breakdowns that can affect the experience of end-users when they act as co-designers. As far as we know, this kind of investigation is the first one in the literature. Our findings can aid developers in the creation of apps more self-guided from which end-users can perform the role of co-designers. Besides, our paper presents all the steps of a robust qualitative study in detail. This rich description of the qualitative study can be seen as an important academic contribution by itself so it allows other researchers to replicate the same study.

The rest of the paper is organized as follows: Section 2 presents the fundamentals and related work; the PWA we developed to our study is presented in Section 3; the details of our study are discussed in Section 4 and its results are in follow Section 5; in Section 6 we return to our research questions to point out the important results and make a comparison with the literature as well as presents the limitations of our study; and finally Section 7 discusses the conclusion and future work.

2 BACKGROUND

2.1 PWA-EU Approach

We adopted PWA-EU to conduct our study. We have proposed it in a previous work (Cardieri and Zaina, 2019). To provide a better understanding, we will explain the approach briefly. PWA-EU approach is an extension of the PWA architecture in which users' preferences are taken into account on the interface adaptation at run-time. Developers and designers should follow the architectural proposal to construct apps from which end-users can modify the interface in accordance with their preferences. The conception initial steps of design is not a part of our proposal. Rather than use methodologies such as user-centered design or design thinking (Sharp et al., 2019), PWA-EU provides a software architecture that allows including features in the apps from which the end-user can act as a co-designer.

Looking at Figure 1, we see on the left side the traditional PWA is shown while our extension is on the right side.

The **User Design Model (UDM)** (A) establishes and combines different *User App Preferences* (E), some examples are UI elements appearance, interaction methods, and content display formats such as data and images. The *User App Preferences* are connected to the app domain. For instance, on a PWA in which end-users create lists, their preferences could be linked to how each list element is displayed. Moreover, the relation between the app and *User App Preferences* should be previously defined by designers and developers. These preferences have default settings and follow meta-design principles, in which users can change their preferences. Developers must select a technology to store these preferences.

The **Management Layer** (B) is responsible for including, editing and deleting the *User App Preferences* on the *UDM*. It can receive two different requests from the PWA:(i) receiving and sending modifications to the *UDM*, and (ii) for sending an updated *UDM* to the *Connection Layer*. The **Connection Layer** (C) has three functions: (i) sending the *UDM* to be stored, (ii) retrieving the *UDM* from the storage, and (iii) sending the latest *UDM* to the *Adaptation Engine*. The first scenario only occurs when the *UDM* was updated by the user on the *Management Layer*. The other scenarios happen when is necessary to load a new UI on the PWA, which can occur when a new *UDM* preference is set or when the user is browsing through the app. The **Adaptation Engine** is the link between the PWA-EU and the traditional PWA architecture. It takes into account the *UDM User App Preferences* to alter the app UI. Moreover, this engine should store the app UI on cache memory and recover it when necessary. We defined the PWA-EU architecture into these three elements and the connection with the *Adaptation Engine* following an adaptation of the event-driven and the layered architectures for software development (Richards, 2015). The event-driven part is relevant since the PWA-EU architecture depends on events triggered by users, such as modifying the *UDM* or loading a new UI.

With regards to EUD, PWA-EU is based on the guidelines presented in the meta-design framework

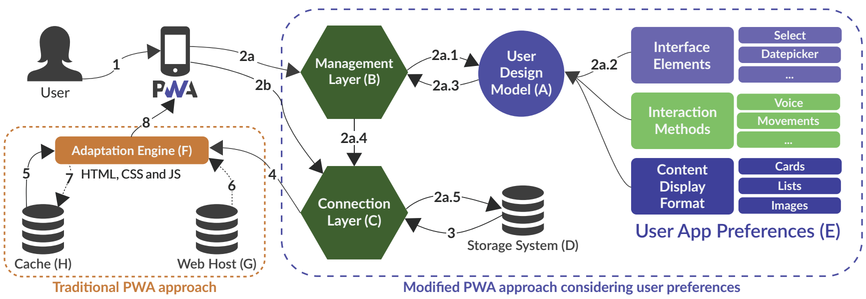

Figure 1: PWA-EU approach.

proposed by Fisher, Nakakoji & Ye (2009) as described in the following: *Support Human-problem Interaction* - Designers and developers should analyze the app domain and its end-users. After this analysis, the *User App Preferences* are defined and included as part of PWA-EU's *UDM*. *Underdesign for Emergent Behaviour* - A PWA developed with PWA-EU has default options before the end-user initial interaction. Due to that, the design of the app is not complete before end-users modified the default options by selecting their preferences on the *UDM*. Moreover, a new design behavior is generated by architectural elements every time the user changes their *User App Preferences* on the app. *Share Control* - Designers and developers are the original meta-designers who define multiple *User App Preferences* during development. At run time, the control of these preferences, that affect app's functionalities and appearance, is transferred to end-users who are acting as co-designers.

2.2 Related Work

As PWA is a recent technology, there are not many works related to it. Biørn-Hansen et al. propose a technical comparison between PWA, Native, Hybrid, and Interpreted apps and concluded there is potential to PWAs unify web and native development without the need of cross-platform frameworks (Biørn-Hansen et al., 2017). Sharma et al. discusses the definition of PWAs and compares their performance to native and hybrid apps (Sharma et al., 2019). In our previous paper (Cardieri and Zaina, 2018), we conducted a UX-based comparison between PWA, Native and Web apps, finding out that all three approaches provided a satisfying experience to end-users. We could not find works in the PWA field that take both interface adaption or EUD into account. In contrast, there are many works on interface adaption for mobile apps, and on EUD (Bueno and Zaina, 2017; Manca et al., 2013; Ghiani et al., 2014; Gullà et al., 2015).

Danado & Paternó proposes Puzzle, a framework in which end-users with no programming experience can develop or customize complex mobile apps and connect their apps to web services and smart devices (Danado and Paternò, 2014). Costabile et al. propose a EUD desktop app based on the software shaping workshop (SSW) method in which a meta-design participatory approach is adopted during the entire software life cycle (Costabile et al., 2008). Namoun et al. (2016) propose a model linking the features of performing EUD in mobile devices to end-users' attitudes towards and intent of doing this. In the studies, the authors considered participants with experience or not on EUD in mobile. The results show that rather than creating apps the end-users have more interest in customizing apps to improve their experience. Nonetheless, these works do not take PWA and interface adaptation into account.

3 DEVELOPING A PWA-EU APP

A Calendar app following the PWA-EU approach was developed to support our study (App available at **https://h1eneas.dlvr.cloud/**). Calendar is a PWA that allows users to manage events and their time (i.e. event name, date, location, category, start, and end time). Calendar was chosen because it represents a common-sense domain avoiding the need for users to learn about the app domain. To build the Calendar, we considered the most popular frameworks in web mobile app design, such as Bootstrap[1] and Materialize[2]. As PWA is a Google proposal based on Material Design, we chose Materialize as the default design for Calendar's UI elements. Material Design consists of guidelines, components, and tools that support the best practices of UI design available as open-source code (Clifton, 2015). We chose Vue.js[3] to develop the front-end because it has a fast learning curve, its applications are smaller to store when compared to the other frameworks, it is easy to use in projects

[1]https://getbootstrap.com/
[2]http://materializecss.com
[3]https://vuejs.org/

and availability of an official Vue.js PWA template[4] (Sheppard, 2017) (Rojas, 2020).

At the start we set up the *User App Preferences* (see Fig 1). After conducting an investigation on the Material Design guide and considering the nature of the app (i.e. Calendar), we decided to cover five *UI elements*: calendar, checkbox, input, select and timepicker. We also introduced a second option in which users acting as co-designers could select. For each element, users acting as co-designers could choose between a Material Design element and a browser-default appearance as part of the *User App Preferences* of the UDM. A browser-default look changes according to the device and browser the user is accessing. For instance, the input from Safari Mobile for iOS shows a vertical scroll for the day, month and year, while on Chrome Mobile for Android it displays a pop-up calendar.

Gestures and voice *Interaction Methods* (see Fig 1) were available. The swipe gesture was selected due to some Material Design components recommending its use, such as lists and cards. The voice synthesis and speech recognition were included considering they became a standard feature on smartphones (Corbett and Weber, 2016). Complementing the *User App Preferences*, *Content Display Formats* were selected to provide users with distinct ways to read the information on the app. Following Material Design guidelines, we defined that users can choose between list and card formats to display data, besides showing or hiding images on the cards.

Each architectural element from PWA-EU and the *Adaptation Engine* are represented on the Calendar app. All three PWA-EU architectural elements (UDM, Management, and Connection Layers) are defined in the My Design section. In this section, participants could select and edit their *user app preferences*. While the *UDM's* values were visually represented by My Design's UI, the *Connection* and *Management Layers* were built as sets of JS functions. *Connection Layer's* functions store and retrieve data from LocalStorage and the *Management Layer's* code changes the values of *user app preferences* on the *UDM*. On the other hand, the *Adaptation Engine* is formed by multiple CSS and JS files that modify *user app preferences* on Home and Include New Event sections.

4 EXPERIMENTAL STUDY

In next section we describe the planning, conduction and analysis our study guided by (Lazar et al., 2017).

[4]https://github.com/vuejs-templates/pwa

4.1 Planning

Participants were invited to take part in the study voluntarily via social networks like Twitter and Facebook. The participants were selected by convenience, according to their availability to take part in the study (Lazar et al., 2017). We obtained two distinct groups of participants who were separated based on their academic and professional experience (Namoun et al., 2016). One group had participants from the technology field (i.e. developers and designers), we named *tech*, and the other had participants from other professional and academic fields, we named *non-tech*. This separation avoids that only individuals with previous knowledge on UI design or development acted as co-designers and indicates whether or not a difference stands between end-users *co-designers* who have a technical profile and those who do not have.

We selected the Communicability Evaluation Method (CEM) (Leitão and Souza, 2009) to conduct our study and guide our analysis of communication breakdowns (RQ1). We used the method to separate into codes the recurring issues and interactions regarding users' communication breakdown situations. CEM is a semiotic engineering-based method that aims to explore communication breakdowns between the designed system and the user through the observation of how a group of users interacts with a particular system. Considering that in our study part of the users are also the designers (i.e. co-designers), these breakdowns can point out whether these individuals' roles as co-designers lead to more satisfying interactions, and understand if even acting as co-designers users still have communication breakdowns.

Moreover, we took the Self Assessment Manikin (SAM) (Bradley and Lang, 1994) to collect the participants' experience after their interactions with the application (RQ2). SAM is a pictograph evaluation method to measure emotional responses from some sort of stimulus. Three dimensions are considered by this technique: pleasure (if the participant had a positive or negative reaction), arousal (body stimulation level from an event or object) and dominance (feeling in control of the situation or controlled by it). The user chooses a value on a scale of one to nine on each dimension, using images, to represent their emotions after interactions. Participants answered questions regarding SAM after each task. Furthermore, when all tasks were accomplished we conducted an interview with four questions to have a broader comprehension of the end-users' perspective.

A pilot test was carried out with two participants. We concluded that no changes were necessary and the study could be run.

4.2 Conduction

The study was conducted over four days in Sorocaba, São Paulo, Brazil. We had a total of 20 participants who were between 18 and 59 years old, median 23 years old. Most participants were undergraduate students or had a degree. All participants accepted the term of consent about the use of data and images for academic ends. Besides the technical profile separation (see Planning section), half of the participants were randomly selected and named *co-designers* due to having an active participation in the setting of the UI design, by selecting their preferences and customizing the app's design. The other ten participants interacted only with features that did not make changes on the UI and were named *non-designers*.

The participants' observation took place individually and the researcher made notes regarding each communication breakdown. Initially, each participant received instructions about Calendar and the conduction of the study. For the *co-designers*, three tasks were proposed. The tasks were specified as follow: **Task 0 - Co-designers** - participants could set the UDM by selecting their preferences regarding UI elements, interaction methods, and display format options; **Task 1 - Include events** - participants included two new events on the app; and **Task 2 - Browse events** - Participants canceled and marked as finished the previous included events. *Non-designers* run only Task 1 and Task 2.

Only the description of the current task was displayed in text format on a laptop screen. We did not introduce a time limit to the participants accomplished the tasks. All the participants used the same mobile device, a Motorola Moto G4 Play running Android 8.1. This avoided that differences in Android operating system versions could introduce bias on interaction data. The participants' interactions with the PWA were recorded by using DU Recorder[5], installed on the mobile device. In addition, the participants' facial expressions and voice were captured by a laptop camera placed in front of the participant. The think-aloud protocol (Sharp et al., 2019) was adopted to provide a better understanding of user interaction and to assist the application of the CEM method. This protocol requires users to speak their thoughts during their interactions. Following the CEM method, we prepared a semi-structured interview that asked a question about the difficulties the participants had in using the app.

4.3 Analysis

The analysis was conducted by crossing-over four data sources (i.e. SAM questionnaire, video recordings, screen recordings, and the main researcher's notes). Approximately, we collected five hours of video recordings from user interactions on the mobile device and recordings of user's faces, and around two hours of audio from the interviews. During a pre-analysis of all video and audio recordings, two samples were discarded. These participants were *co-designers*, from both *tech* and *non-tech* groups, who did not complete Task 0. In the end, we had 18 participants, from which eight acted as *co-designers* and the others as *non-designers*. Due to the sample size of 18 participants, we decided not to conduct an inferential statistical analysis. We carried out three rounds of analysis with at least two cycles of data exploration for each one. In the first cycle, the first author of this paper explores the data, and after, in the next cycle, the first and second authors together revised, refined, and consolidated the outcomes.

In the first round of analysis, the videos containing the users' interactions on apps and facial expressions were put together on the same video aiming to enable easier and more precise identification of each evidence of a communication breakdown. For this, we used the iMovie Software[6]. Regarding the interview, we transcribed to text all conversations recorded on audio between the users and the researcher. After all the videos were combined, we started CEM's tagging step. The first author of this paper watched all video recordings twice, took notes of when, why and where it occurred, and assigned a tag when a communication breakdown was identified. A spreadsheet was used to support all the analysis. We used the 13 tags proposed by the CEM method (Leitão and Souza, 2009). These tags are natural language expressions commonly found in human communications, which the participants might utter during the thinking aloud process.

In the second round, the chunks that were tagged were revisited for the identification of the main communication breakdowns. Each tag was listed and analyzed in two perspectives: (i) the frequency and context of occurrence which was identified by listing when, where and the probable reason each tag occurred, and (ii) the existence of pattern in sequences of tag types, such as grouping tags connected to the similar communication breakdowns on multiple or single participants. In each step of tagging, the first author conducted a double-checking of the results.

In the third round, we did a crossing-over among

[5]http:/www.duapps.com/product/du-recorder.html

[6]https://www.apple.com/imovie/

the issues that have caused the observed breakdowns, with the participants' profile, SAM answers, recordings and interview data.

5 FINDINGS

We organized our findings in two subsections considering the two RQs we should answer. Table 1 will support us in our discussion regarding our findings. It shows the profile data of the participants and their SAM feedback.

5.1 Communication Breakdowns

We analyzed the communication breakdowns that were caused by the *co-designers* choices because only these participants interfered with the app's design. These are problems influenced by the user preferences selected when participants were acting as co-designers. Moreover, we counted seven communication breakdowns which came up from five participants on a total of eight *co-designers*. The breakdowns were categorized into four of the 13 tags (identified by letter T) provided by CEM. Figure 2 shows the tags that represent the breakdowns that arose when the users were interacting with the Calendar app. The rightmost diagram indicates which breakdowns also occurred as a consequence of co-designer actions. Following we concentrated on discussing the tags from the third diagram. The other breakdowns are out of the scope of this work due to they are related exclusively to UI elements and technological expertise issues.

T6 - What happened? tag is identified when users repeat an operation because they could not see or understand the effects of their actions. We saw evidence of T6 from [P4] interaction on Task 2. Playing the role of co-designer (i.e. performing Task 0), [P4] changed the default design of *content display format* (see the content display format on Fig 1) from card to list. Explaining the preference after the execution of Task 0, [P4] said: *"I prefer the list rather than card viewing...it shows the same data but allows me to see more data at the same time"*. Additionally, the list format changed how the cancel and finish buttons were displayed in a way the buttons contained only symbols (i.e. an X and a checkmark, respectively) representing the actions instead of the text format from when the card format was selected. While performing Task 2 [P4] was not sure which button canceled an event. After a time of hesitation, [P4] pressed the cancel button and the app displayed a modal window requesting the participant to confirm the action. Rather than confirming the cancellation, [P4] closed the modal and reopened it right away, this time confirming the action. In the interview [P4] stated *"That was very practical, I just tested it once to be sure I was clicking on the correct button"*.

T8 - Where am I tag represents the communication breakdown when a user did not find a particular feature by pausing and searching it. T8 was identified on [P8]'s interactions on Task 2, who likewise [P4] selected the list as default *content display format*. Commenting on the selection, [P8] said: *"It's an advantage as is faster to check events using the list format"*. Nonetheless, [P8] was insecure about which button would perform the action to mark an event as finished, as the buttons had only symbols and not text. S/he stated: *"Mark the event as finished? ... Let me click here ... oh, ok! .. Yay!"*. By analyzing this snippet, we noticed that initially s/he was not sure which UI element would perform this action. Yet, [P8] figured it out in a few seconds and explained this breakdown over interview *"I didn't realize the finalize button was there, I initially tried to click over the list"*. However, a couple of minutes after this statement [P8] recalled this issue affirming *"Finalizing an event was easy."*.

The **T9 - Oops** tag occurs when a user momentarily makes a mistake and immediately corrects it. S/he sees that s/he has made a wrong step and usually activates the "undo" function immediately. This breakdown was identified on [P7]'s interactions on Task 2, a *tech co-designer*. Resembling [P4] and [P8], [P7] selected the list as the preferred *content display format* on Task 0. S/he stated: *"I prefer the list because it fits more data onto the screen, it's very clear and not cramped."*. Yet, s/he had issues to understand the difference between cancel and mark as finished buttons. While trying to finish an event, [P7] spoke *"The button is asking me if I want to finish an event... I don't want to finish .. wait? Is it the same thing?... finish an event, ok."*. By [P7]'s speech, we observe a misunderstanding regarding the verbs cancel and finish. Over the interview, s/he explained: *"The action buttons were not clear, I understand one of them is positive and the other is negative. Still, the message was very similar in both actions"*.

On the **T13 - Why doesn't it?** tag, the user is trying to make sense of the designer message by repeating the steps of previous unsuccessful communication in order to find out what went wrong. The issue experienced by [P7] in the previous paragraph is also connected to T13. On Task 2, [P7] repeated the 'mark as finished task' until s/he understood the difference between this and the cancel action. Additionally, T13 also occurred with two other partici-

Table 1: Participants' profile: P/A Experience - Professional/Academic Experience, and SAM results: PI - Pleasure Index, AI - Arousal Index, DI - Dominance Index.

Participant	Group	Technical Profile	P/A Experience	Task 0			Task 1			Task 2		
				PI	AI	DI	PI	AI	DI	PI	AI	DI
P1	Co-designer	Non-tech	2-4 years	8	7	9	9	9	9	9	9	9
P2	Co-designer	Non-tech	N/A	7	6	8	9	8	8,5	9	9	9
P3	Co-designer	Tech	5 years or more	8	9	9	7,5	7,5	8,5	9	9	9
P4	Co-designer	Non-tech	1-2 years	6	6	3	8	8,5	8,5	8	8	7,5
P5	Co-designer	Non-tech	Less than a year	8	9	7	9	9	9	9	9	9
P6	Co-designer	Tech	2-4 years	7	9	8	8	9	8	8	9	7
P7	Co-designer	Tech	2-4 years	6	8	8	5,5	5,5	6,5	5,5	4	5,5
P8	Co-designer	Tech	5 years or more	7	5	9	9	9	7,5	9	9	9
P9	Non-designer	Non-tech	5 years or more	-	-	-	9	9	9	9	9	9
P10	Non-designer	Non-tech	2-4 years	-	-	-	8,5	9	8,5	9	9	9
P11	Non-designer	Non-tech	5 years or more	-	-	-	7,5	7,5	7,5	9	8	9
P12	Non-designer	Tech	5 years or more	-	-	-	7,5	8,5	9	9	9	9
P13	Non-designer	Non-tech	1-2 years	-	-	-	7	7,5	6,5	7	9	6
P14	Non-designer	Tech	5 years or more	-	-	-	7,5	9	9	8	9	9
P15	Non-designer	Tech	1-2 years	-	-	-	7	8,5	7,5	7,5	8,5	7,5
P16	Non-designer	Non-tech	1-2 years	-	-	-	7,5	7,5	8	9	9	9
P17	Non-designer	Tech	5 years or more	-	-	-	7	8	5	5	7,5	3,5
P18	Non-designer	Tech	5 years or more	-	-	-	8	9	8	8,5	8	9

pants on Task 1, in which participants had to include an event. [P1] and [P2], *co-designers* from the *non-tech* group, selected the Materialize's *datepicker* instead of the browser-default. The default behavior of Materialize's *datepicker* displays the current day with a distinct font color that led participants to believe a date was selected. Still, in order to choose a date, users had to touch over a day and it would acquire a different background color. This behavior is a feature from Materialize, which is not considered a design error by the library. Both participants did not comment on why they selected this *datepicker* instead of the second option, which did not present this behavior. Yet, [P1] explained *"I did not enjoy the datepicker because instead of performing two commands I wish I could complete it in one."*. Conversely, [P2] did not state difficulties. Other three participants selected this *datepicker*, [P3] from the *tech* and [P4], [P5] from the *non-tech* group. However, [P4] had the same breakdown with the Materialize UI element on Task 0, which lead him/her to select the other *datepicker* option.

As Materialize's *datepicker* was the default on the Calendar app, we can compare the T13 breakdown with the *non-designers*. For *non-designers*, four (P11, P13, P15, and P17) of the ten participants experienced a similar issue. Two (P15 and P17) of these four were from the *tech* group. This comparison points out that even people who are acquainted with technology may have issues understanding Materialize's *datepicker* behavior. Most *co-designers* from the *tech* group selected the second option, which displays a UI element associated to the browser.

Even though three participants (P4, P8, and P7) had distinct issues related to the list and action buttons on Task 2, two other *tech* participants, [P3] and [P6], also selected the list as their *content display format* preference. Both [P3] and [P6] did not experience breakdowns, instead, both stated in the interview that the action buttons were very clear. As the list was not available as *content display format* for participants who did not act as *co-designers*, we could not make a relation with the *non-designers* participants.

Further, we looked at the results of the interview. One question asked whether the *co-designers* felt they had better interactions due to their design choices. Six from eight participants felt positive about this question, [P8] felt neutral and [P2] disagreed. [P2] stated *"The choices don't change a lot of things"*. Yet, s/he was a *non-tech* participant with initial difficulties in understanding how the design options would be later applied. The *tech* participant [P8] said the choices did not interfere with posterior interactions. The other six participants explained the preferences selection made the navigation easier and more pleasant to interact. Some examples are *"The app was more pleasant as it identifies with your choices."*[P3]; and *"The app gets easier to interact"*[P4].

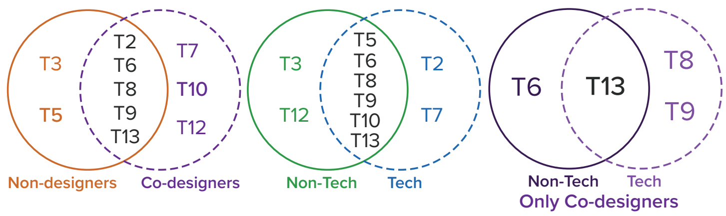

Figure 2: Participants communication breakdown tags divided by co-designers/non-designers, tech/non-tech and co-designers from both tech/non-tech.

5.2 UX Perception

Our discussion on UX perception is performed on a holistic overview throughout the interpretation of the users' feedback from SAM. Table 1 summarizes the SAM dimensions and the participants' responses per task. When we look at participants' results divided by their technical profile, we notice a contrast between them. Hence, Figure 3 shows a comparison of both groups on the *co-designers'* feedback on Task 0. Further, the SAM medians for *co-designers* are higher on Task 1 in which interactions with UI elements are linked to user app preferences. Yet, there were no differences in the SAM values for Task 2, as users' choices were not as visible as Task 1.

By associating the results of Table 1, Figure 3 and taking into account all the *co-designers* (i.e. tech and non-tech), we see an outlier regarding dominance index. This is a consequence of [P4] having selected value 3 for this index. By checking the videos of the participants' interactions, we noticed that three *non-tech* users (i.e. [P2], [P4] and [P5]) had difficulties in understanding how to initiate Task 0 and were confused about their role as co-designers. Yet, they were having doubts about why and how their preferences would affect their interactions. [P4], for instance, was browsing through the design options for a minute and asked the researcher for help: *"I can't understand what I should do here"*. On top of that, [P2] had questions about the consequences of the changes: *"Where can I see this element if I choose it?"*. Moreover, [P5] said: *"But how do I know what is the difference between this or that checkbox?"*. Briefly, the researcher answered all the questions and the participants had no further issues regarding their initial difficulties. Even though [P4]'s SAM values appear as outliers when we take all *co-designers* into account, his/her dominance index value is not an outlier when we focus only on *non-tech* participants. As pointed out in Figure 3, *non-tech* individuals who took the role of *co-designers* selected lower values on arousal and dominance SAM dimensions, which might be the cause of this remark.

[P2], [P5] and [P7] had difficulties in acting as co-designers. However, they struggle more on choices of *interaction methods* (see interaction methods on Fig 1). Both from the *non-tech* group, [P2] and [P5] asked the researcher for help, and [P2] stated: *"This speech recognition, what does it specifically do?"*. Still, [P2] was confused about other design choices such as *swipe movement* and the *datepicker*. In both situations, the researcher gave a brief explanation about what the design choices meant and participants continued their tasks. Yet, the *tech* group participant [P7] stated that *"I don't like to use voice, I don't like voice synthesis or speech recognition ... I don't understand why both methods are separated, but it's fine"*. This issue could also be one of the causes of [P2] having attributed lower values for pleasure and arousal indexes. On the other hand, [P5] selected high values for both pleasure and arousal indexes. As the only representative of the *tech* group, [P7] selected 6 for pleasure index. However, [P7] chose high values for the other SAM indexes pointing out that the issue did not affect the experience.

By observing Figures 4 and 5, we see the homogeneous feedback of the participants independently of the task and their group. Task 1 boxplots show outliers linked to [P7] and [P16]. Both participants are from the *tech* group, yet, [P7] was a co-designer and [P16] was not. Comparing the data from both CEM and SAM methods, we found out that [P7] and [P16] had a common issue that was also experienced by [P1], [P2], and [P3]. The issue came up during the use of *timepicker* element, in which they had to include an event with a specific time slot. Actually, all the participants had some kind of difficulty while select-

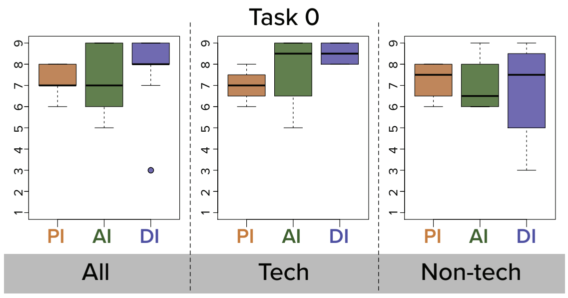

Figure 3: UX perception of with Task 0.

ing a precise time slot. We noticed this issue on both *timepicker* options, materialize and web pattern. During the interview, [P16] related issues regarding the *timepicker*'s accuracy: *"It's nice to have a timepicker that spins to a precise time, but I had many difficulties trying to select both zeros from 15:00. I'm not sure if it is too accurate or not accurate at all"*. No other participants commented on this issue. Taking a look at SAM indexes of [P1], [P2] and [P3], we notice that this issue did not affect their UX. Nonetheless, [P3] had lower values when compared to [P1] and [P2]. The results showed that this barrier has affected only the SAM indexes of the *tech* participants.

The issue related to the *datepicker* described in the previous subsection affected only part of the participants. When we observe [P1] and [P2] SAM results, we notice they did not select lower indexes on Task 1. The *non-designers* (i.e. P11, P13, P15, and P17) who had this issue selected lower values on SAM indexes for Task 1. This points out that the *co-designers*' experience was not affected by this breakdown, yet, the *non-designers* had a less satisfactory experience.

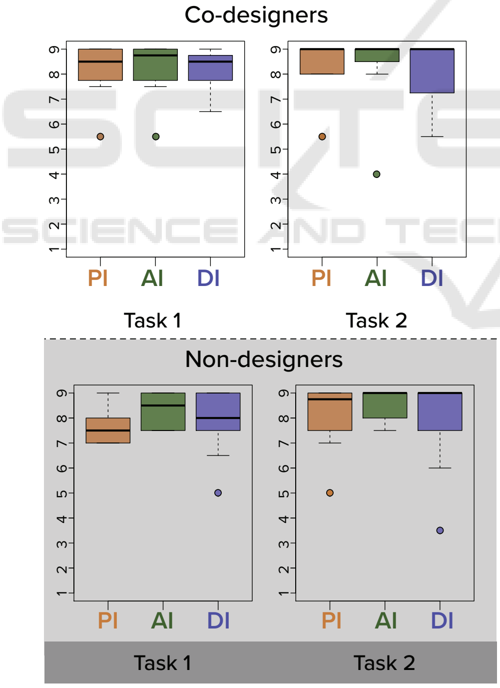

Figure 4: Boxplots with SAM results categorized by participants role.

Also connected to the communication breakdowns, the issue regarding the list UI element did affect *co-designers* UX. In Figures 4 and 5, we see the outliers in the boxplots of *co-designers* (pleasure and arousal indexes) and of techs (arousal index) group from Task 2. Besides that, all of SAM indexes of [P4] are pointed out as outliers on the *non-tech* boxplot. Yet, the values from [P4] did not come as outliers on the *co-designers* boxplot. The experience reported by [P8] showed the communication breakdown s/he has faced did not bring consequences to his/her experience due to SAM values are high.

The other two outliers on Task 2 for pleasure and dominance indexes were found from [P12] feedback when seeing as the *non-tech* participant. His/her issues are related to his/her own expectations regarding the app (i.e. s/he wished a specific functionality existed), not their UI elements or the PWA-EU approach. Instead, the lower values arose when the participant wanted extra functionality on the app in which the finished and canceled events could be restored. [P12] stated: *"Wow, the event I marked as finished just vanishes? I'm sad"*. Likewise, [P12] and [P16] outliers presented in Task 2 for pleasure and dominance indexes on both non-designers and *tech* boxplots are linked to the same expectation.

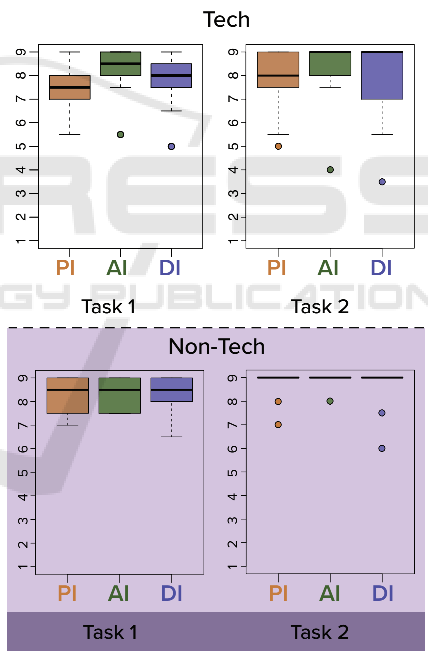

Figure 5: Boxplots with SAM results categorized by participants experience.

6 DISCUSSION AND STUDY LIMITATIONS

Considering the communication breakdowns results, we answer the RQ1 *"Which communication breakdowns come up when users play the role of co-designers in a PWA?"*. Even when users acted as *co-designers* they experienced communication breakdowns. This remark is affected by users' technical background, such as programmers and designers who are used to building and designing applications. Tech participants had fewer breakdowns as they had more expertise in the behavior and functionality of different UI elements than *non-tech* ones. Although EUD brings interest and motivation to *non-tech* end-users, their lack of technical skills makes them not engage as *co-designers* (Namoun et al., 2016).

Supporting by SAM results we can answer RQ2 *"How are users' perception of UX when interacting as co-designers?"*. By playing the role of *co-designers* the participants had a more positive perception as their active participation in the app design could improve their experience. This remark could be noticed especially in the pleasure index. When considering the technical profile, the *tech* group demonstrate less satisfaction than the non-tech. However, while playing the role of *co-designers* the *non-tech* individuals felt less dominant and aroused comparing to the *tech* ones. Technical issues can introduce situational limitations to *non-tech* end-users (Casadei et al., 2017). These limitations are any kind of problem that comes up from environmental characteristics and may jeopardize the UX (Henry et al., 2014). One important motivation for end-users engaging in EUD actions is the improvements that it can bring to their experience (Fischer et al., 2017). Yet, one of the biggest challenges to overcome is to simultaneously give end-users the empowerment of designing apps and provide ways to support them with how to do EUD (Namoun et al., 2016). In order to provide more guidance, we could establish guidelines for the development of the PWA-EU.

Since most issues pointed out in the results are related to three UI elements (datepicker, timepicker, and list), we can discuss if the identified breakdowns are connected to the interaction with UI elements. As reported in our previous paper (Cardieri and Zaina, 2018), despite bringing satisfaction, datepickers can cause confusion and frustration on PWA users. Moreover, users have issues while including data via forms on mobile apps as these elements have not changed much since their first design. Finally, lists seem like a practical design for users, yet it raises serious accessibility concerns (Casadei et al., 2017). Still, likewise our previous study (Cardieri and Zaina, 2018), participants achieved a satisfying UX even with issues when interacting with the UI elements.

We took different actions as the sample of our work can be considered a limitation (i.e. 18 participants). First, we adopted four distinct data sources that allowed us to triangulate data that provides reliability to the analysis. Yet, we assured all participants used the same mobile device in order to avoid bias which could be caused by different Android versions. We also explored the data on distinct lenses (i.e. SAM and CEM) and consequently getting rich discussions of the results. We ensured all selected participants were frequent users of mobile devices in order to avoid problems related to the interaction with the mobile platform. Still, our work is limited to the use of certain UI elements, which were part of the user app preferences and are connected to the user's experience, as pointed out in the discussion.

7 CONCLUSION AND FUTURE WORK

This paper presented an investigation about end-users acting as co-designers on PWAs. The findings revealed that individuals with technology background were less satisfied, but felt more dominant when acting as co-designers. Conversely, grouping participants as those who acted as co-designers and the ones who did not, we noticed the co-designers group had more satisfying interactions on the posterior task when compared to the ones who did not include their preferences into the PWA.

Our work contributes to the discussion of how end-users could actively participate in the design. The results show that there are some difficulties in playing the role of co-designers and these can have a direct impact on the overall UX. Working on more guided mobile apps could be a start point for achieving an inclusive environment for end-users. We also present an important discussion regarding the potential of combining PWAs and EUD. PWA-EU could be seen as a contribution for developers of apps in the sense it arranges the responsibilities from the architectural perspective of the application.

As future work, first, we intend to refine the PWA-EU approach by adding recommendations on how developers can provide more guidance during interaction and consequently support end-users in their role of co-designers. For instance, only after the user interacts with a user app preference (i.e. a UI element) the different preference options are displayed. Further, the app section in which the user can select their preferences is progressively built according to user interactions.

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