Case Study on Mobile Applications UX: Effect of the Usage of a Cross-Platform Development Framework

Master Thesis

Esteban Angulo Cevallos

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Author: Esteban Angulo Cevallos
Systems and Computer Engineer
Pontificia Universidad Católica del Ecuador

Supervisor:
Xavier Ferré Grau
Ph.D. in Computer Science
Universidad Politécnica de Madrid

DLSIIS
School of Computer Science
Universidad Politécnica de Madrid
I dedicate the effort of this work to people who have been mainstays in my life and who have walked with me through this journey.

“El éxito es un camino donde la ciencia permite descubrir hasta donde el hombre puede llegar”.

Pablo Camino

“Success is a journey where science allows discover as far as men can get”.

Pablo Camino
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Abstract

Cross-platform development frameworks for mobile applications promise important advantages in cost cuttings and easy maintenance, posing as a very good option for organizations interested in the design of mobile applications for several platforms. Given that platform conventions are especially important for the User eXperience (UX) of mobile applications, the usage of a framework where the same code defines the behavior of the app in different platforms could have a negative impact in the UX.

The objective of this study is comparing the cross-platform and the native approach for being able to determine if the selected development approach has any impact on the users in terms of UX. To be able to set a base line under this subject, a study on cross-platform frameworks was performed to select the most appropriate one from a UX point of view.

In order to achieve the objectives of this work, two development teams have developed two versions of the same application; one using a framework that generates Android and iOS versions automatically, and another team developing native versions of the same application. The alternative versions for each platform have been evaluated with 37 users with a combination of a laboratory usability test and a longitudinal study.

The results show that differences are minimal in the Android version, but in iOS, even if a reasonably good UX can be obtained with the usage of this framework by an UX-conscious design team, a higher level of UX can be obtained directly developing in native code.
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1. Introduction

This introductory chapter presents the motivation, the objectives and the explanations for conducting this study and showing the results in this Master Thesis. Additionally, the structure of the document is illustrated.

1.1. Motivation

In recent years, the growth and usage of smartphones and mobile devices has changed the communication habits of the population and the development of mobile applications is supporting their daily life activities [Di Giovanni et al, 2012]. People use mobile devices and mobile applications for reading newspapers, listening to music, interacting in social networks, playing, communicating, etc.

There are over a million apps (for mobile applications) available to download in the Apple’s App Store for iOS devices alone [Apple, 2014], so competition is fierce to get users’ interest and loyalty in the app market. In this scenario, UX (User eXperience) is the key differentiator [IBM, 2012].

The market offers many different options for starting the development of mobile applications. One of the main objectives of the market is the creation of applications that can be used and work perfectly on the different platforms that currently exist on the mobile device world. In fact, the selection of a proper technology and a proper framework to develop the mobile app are the challenges that development teams all over the world are facing right now [Humayoun et al., 2013].

From the spectrum of available mobile platforms, iOS and Android are the leaders and dominants on the mobile applications market. In fact, according to a study of IDC Worldwide Mobile Phone Tracker [Llamas et al., 2013] Android and iOS combined form the 91.1% of the Worldwide Smartphone OS market on 2012. In 2013 the market share is reduced but the tendency remains the same, as some competitors gain some space on the market. As stated on IDC’s Worldwide Mobile Phone Market Forecast [IDC, 2013], this tendency will be maintained until 2017 when iOS and Android will have 86.2% of the market share.

Therefore, for an organization choosing to develop only for two platforms, Android and iOS would be the best choice in order to aim for the biggest user base. We have chosen these two platforms for this study.

Each mobile platform has its own style for how the interaction between the user and the application happens, defined in its specific UI (User Interface) design guidelines [Apple, 2014b] [Google, 2014], and through informal platform conventions. Based on the differences between platforms, usually the approach is developing independent projects for each platform which impacts on costs for the enterprises as more money and resources are required.

Cross-platform development frameworks offer a way of saving resources in the aim of covering different platforms. These frameworks allow the developers to create applications for multiple platforms and devices – usually smartphones or tablets – from within the same design tool.
The popularity of cross-platform development frameworks has increased as these tools offer several benefits to develop an application for targeting several mobile platforms at once. In fact, cross-platform tools allow software companies to target multiple platforms, to reuse developer skills, share codebases, synchronize releases and reduce support costs.

Despite the benefits of developing a mobile application with cross-platform frameworks, this approach also has some drawbacks like performance, access to specific hardware features, time to access to new OS upgrades, design challenges, UX, etc.

From the possible drawbacks, UX is especially important. The performance and generating a great experience to the users are important to engage them to use the application and to the subsequent success of the product. Additionally, visual impact is also relevant, but it requires additional characteristics to provide a high level of UX. An application that looks really nice but is neither effective nor efficient may cause a reduction of the frequency of use.

Specifically about UX in mobile applications, native ones provide more responsive and fluid interfaces and interactions than cross-platform especially for animations and gestures [Madaudo et al., 2013]. This difference is caused due to the fact of reduced accessibility to hardware resources (in specific cases) or due to the different approaches of managing the graphical components. The approach used to face challenges of creating a good UX on mobile applications must fulfill the specific platform conventions. Depending on the project's nature, the UX and the interaction design approaches may vary. Moreover, the framework selected plays an important role as some of them face the conventions on a different way. The different approaches are explained in section 2.4.

Due to the popularity of mobile applications and because users of a platform are used to interact with their applications and they expect any new features of the apps follow the same conventions. The users may get confused if those new features are presented differently. The UI considerations are not only about how the elements look on the screen, they are also related on the different ways that each platform handles events or interactions.

The user experience for Android and iOS devices is different [Fling, 2009]. App designers need to take into account the particular flavor or interaction for iOS or Android in order to design the app consistent with standard/typical interaction strategies in each platform. This is emphasized by design recommendations for app designers to follow platform consistency [Clifton, 2013], valid also for any kind of handheld devices expressed as "conform to platform conventions" [Harton et al., 2012]. When an app is designed following platform standards and usual interaction strategies, users will be able to build on their previous app usage experience, therefore improving their learning curve and their overall satisfaction.

This study is focused on analyzing and evaluating the user experience generated in an application developed using native and cross-platform approaches. To accomplish these objectives, two studies were performed: laboratory and a longitudinal studies of the application in which the users have to perform and complete certain tasks and report their own experience interacting with the application.

The application used is the mobile application of the School of Computer Science (ETSIINF in its Spanish acronym) at Universidad Politécnica de Madrid. This application allows the members of the university community to have access to important information and data of the University from their smartphone without
necessarily having to access the official website. In this work, the application will also be known as ETSIINF-app; also the term “app” will be used for referring to mobile applications.

The native versions for iOS and Android, and the cross-platform version have been developed by independent teams of developers, following a UCD (User-Centered Design) approach. The author of this research work has been responsible for the development of the cross-platform versions, as their development was necessary for the success of the research, additionally to the work of planning, carrying out and analyzing the results of the usability evaluation of all the different versions.

1.2. Objectives

The above-mentioned difficulties in using cross-platform frameworks with relation to platform conventions, lead to several open questions: what happens when using a cross-platform development framework with the differences in terms of interaction design between platforms? From a UX point of view, we would expect that these frameworks would take this into account, but to which extent? Do development teams who opt for the use of a framework obtain a product that offers an impoverished UX? The objective of this work is to explore these questions, by studying how the usage of a cross-platform development framework affects the user experience in terms of consistency with platform-specific standards and conventions.

More specifically, the objective is to identify possible differences in the UX experienced by a representative set of users of a mobile application between a native version of the application and one created with a cross-platform framework. Basic usability aspects as user efficiency and effectiveness will be also measured, along with user impressions about the app in comparison with other apps he or she is used to.

The starting point for studying the possible limitations of cross-platform development frameworks in terms of UX of the developed apps was to select the best one from a mobile UX point of view. From the several options available on the market, a selection study was performed to select the best option for developing the cross-platform prototype by an organization interested on developing software and being aware on UX [Angulo et al., 2014]. Based on the study mentioned, the selected framework is Titanium Appcelerator as it offers differentiated behavior for each platform automatically.

1.1.1. Specific Objectives

- Design and develop a prototype version of the ETSIINF-app using the chosen cross-platform framework.

- Elaborate an evaluation plan of both kinds of versions (native vs. cross-platform framework) in terms of user experience.

- Evaluate the user experience for a specific group of users according to the evaluation plan.

- Analyze the results, comparing the behavior and satisfaction of users with each version of the application.

- Identify the main causes of dissatisfaction in users (if any).
1.3. Document structure

The present chapter includes the introduction, the motivation and objectives behind this work.

Chapter 2 contains the state of the art for being able to set the context and gives the background information on which is based this thesis. It contains a research on cross-platform frameworks available on the market; the differences between the native and cross-platform approaches for develop mobile applications; the concept of usability and the concerns that are required under this subject for having an excellent final product; the user experience (UX) in mobile application including the different approaches on which the designers can rely for generating a good interaction between the users and the application; and finally a bibliographical research on usability evaluations between native and cross-platform approaches.

On Chapter 3 is detailed all the process followed on the development of the cross-platform prototype and its iOS and Android versions. This section includes information about the User Center Design (UCD) approach used on the development of the prototype. The cross-platform framework used for this development is described highlighting its characteristics and the advantages and disadvantages at the moment of programming. Also this section contains the evaluation process and the obtained results of the first prototype version and the improvements to be done on the second version, which was used as the cross-platform version for the study of this work.

Chapter 4 contains the baseline for generating the usability tests including the methodology used and the points taken into account at the moment of designing the usability tests. It also includes the preparation and the general description of the laboratory and the longitudinal studies that were part of this work for being able to evaluate the mentioned development approaches.

Chapter 5 contains the results obtained on the usability study both in the laboratory test and in the longitudinal study. The results are separated in two sub-sections: performance measurement and UX measurement via questionnaires. This section also includes the possible threats to validity of the results and the analysis of the values obtained with its interpretation to determine the preferences of the users.

Finally, in chapter 6 are stated the conclusions of this thesis and the possible lines of work in order to continue the investigation on the same topic in the future.

1.4. What is not contained in this thesis

As the main purpose of this thesis is to evaluate usability and user experience of a mobile application developed using native and cross-platform approach, this work will not describe in depth the development process of the cross-platform application, only the relevant parts that may affect the validity of the results. Moreover, the process to select the cross-platform framework to develop the prototype is also out of the scope of this thesis and therefore this work just includes an overall description in section 2.1.
2. State of the art

2.1. Cross-platform Framework Research

Cross-platform framework tools are becoming more popular as they allow developers to create a mobile application than runs in several mobile platforms based on the principle of “write-once-run everywhere” as mentioned by Rosario Madaudo and Patrizia Scandurra [Madaudo et al., 2013]. This principle is not as ideal as it sounds because it depends on the nature of the application, the targeted platforms and the user experience that is desired. To fulfill all these requirements, it may be necessary to implement specific code for each platform to generate the expected results.

There is a wide offer of cross-platform frameworks currently on the market; most of the existing cross-platform environments use three key technologies: HTML5, JavaScript (JS) and Cascade Style Sheets (CSS). Depending on the framework, this combination of technologies may vary or can be totally different as there are tools which work with Ruby, C# or a combination of JavaScript plus its own API [Humayoun et al., 2013] [Madaudo et al., 2013].

2.1.1. Classification of Cross-platform Frameworks

As there are different approaches for the development of cross-platform mobile applications, we considered the following classification [Banerjee, 2011] and [Banerjee, 2012] to group the frameworks into categories. This classification contains 19 different options grouped by the five available approaches of cross-platform mobile application development. Moreover, an important attribute considered while evaluating the tools was the license and its costs. We generated a list based on the mentioned classification adding the availability of each tool.

- **Mobile Web:**
  These tools are primarily JavaScript libraries which in combination with suitable HTML5 and corresponding CSS render a mobile website on different types of devices. Some of these tools can work in conjunction with hybrid tools and the result can be packaged as a native application.

  **Examples:**
  - **Open source:** iUI, jQuery Mobile, SenchaTouch.

- **Visual Tool:**
  They provide a visual interface where elements / widgets are dropped into the screen and the internal application plumbing is taken care by the tool. The result is either a native application or a mobile website depending on the tool.

  **Examples:**
  - **Free Version:** Net Biscuits.
  - **Trial Version:** AplicationCraft.
  - **Paid only:** Kony, Verivo.
Case Study on Mobile Applications UX: Effect of the Usage of a Cross-Platform Development Framework

- **App Generator:**
  In this category the tools invite the developers to write their applications in a specific language but the tool translates it into a deployable native application for different platforms. The deployable application may include a runtime engine or a virtual machine. The programming language varies from tool to tool.

  **Examples:**
  - **Open Source:** Titanium Appcelerator, RhoMobile, Xamarin-Mono, MoSync.
  - **Trial Version:** Flex (Adobe).

- **Hybrid App:**
  This category of tools provide a platform specific shell application which has the capability of rendering prepackaged HTML pages and extends the HTML capability through APIs which allow access to device specific features. Some of them include libraries to render platform-specific UIs.

  **Examples:**
  - **Open Source:** PhoneGap, Intel XDK.
  - **Trial Version:** WorkLight.

- **Game Builder:**
  This is similar to the previous category, but these tools are primarily targeted for game development. They have a much richer UI library and may even have 3D graphics capability. Some of them use special languages like Lua or LiveCode. Their cross-platform capability may extend beyond mobile devices.

  **Examples:**
  - **Free Version:** Unreal.
  - **Trial Version:** Corona, Unity.
  - **Paid only:** Bedrock.

2.1.2. Comparison and Selection of Cross-platform Frameworks

From the frameworks mentioned in the classification above, the paid tools and frameworks to develop games were discarded as well as the frameworks that did not cover the desired scope.

The list was reduced to eight candidates: PhoneGap, Sencha, jQuery Mobile, Intel XDK, Titanium Appcelerator, RhoMobile, Xamarin and MoSync. The information available for each framework was studied, considering the following criteria:

- To offer support for Android and iOS native app development, to be able to compete with directly-developed native apps.
- To be based in a well-known programming language, to ease adoption by developers.
- Free availability.
- To include its own IDE (Integrated Development Environment) or to be compatible with widespread IDEs, to ease development.
- To offer access to device APIs, to be able to offer the same level of functionality than native code.
- To have a high use rate among developers.
Table 2.1 contains a summary of the principal characteristics of the eight pre-selected frameworks.

**Table 2.1: Comparison between cross-platform frameworks.**

<table>
<thead>
<tr>
<th></th>
<th>Type</th>
<th>Language</th>
<th>Availability</th>
<th>Modeling UI</th>
<th>IDE</th>
<th>Access device HW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PhoneGap</strong></td>
<td>Hybrid App</td>
<td>HTML5</td>
<td>Open Source</td>
<td>External JS-CSS libraries</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Sencha</strong></td>
<td>Mobile Web</td>
<td>HTML5</td>
<td>Open Source/Paid</td>
<td>JS-CSS library (itself)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>jQuery Mobile</strong></td>
<td>Mobile Web</td>
<td>HTML5</td>
<td>Open Source</td>
<td>JS-CSS library (itself)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Intel XDK</strong></td>
<td>Hybrid App</td>
<td>HTML5</td>
<td>Open Source</td>
<td>External JS-CSS libraries or Drag&amp;Drop interface</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Titanium Appcelerator</strong></td>
<td>App Generator</td>
<td>JavaScript</td>
<td>Open Source</td>
<td>Own API (native components)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>RhoMobile</strong></td>
<td>App Generator</td>
<td>Ruby</td>
<td>Open Source</td>
<td>Style sheets included</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Xamarin</strong></td>
<td>App Generator</td>
<td>C#</td>
<td>Open Source</td>
<td>UI layers included</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>MoSync</strong></td>
<td>App Generator</td>
<td>C++ / HTML 5 - JavaScript</td>
<td>Open Source</td>
<td>Own API (native components)</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

After analyzing the characteristics and properties of the eight candidates, only the following three tools complied with all the requirements: Titanium Appcelerator, PhoneGap and Intel XDK.

These three tools were evaluated with a case study, consisting on an app to show the bus timetable for a campus, in order to base the evaluation in hands-on experience with each framework. The test app interaction design included several screens, so that to be able to evaluate how each framework deals with navigation issues. While developing the test app with each one of the three frameworks, we evaluated them according to two different perspectives: The developer point of view (the tool advantages for reducing the cross-platform development effort) and the UX expert point of view (how well the framework produces an interaction design in concordance with Android and iOS conventions).
The three tools offered a good perspective of usage for developers, excelling Titanium Appcelerator and Phonegap in this respect. Titanium Appcelerator (referred as Titanium in the rest of this work) was finally chosen because it is the one with best results from a UX expert perspective. In this respect, it is the only one to adapt the UI for the generated apps to some differences between Android and iOS UI guidelines, as for example the tab bar: On iOS the tab bar always appears at the bottom edge of the screen [Apple, 2014b]; alternatively, tabs on Android are placed on a Top Bar, just below the Action Bar in the top part of the screen [Google, 2014]. Titanium offers this differentiated behavior in the code generated for each platform, adapting the visual components automatically for providing native behavior.

Therefore, we consider Titanium the best choice between freely available cross-platform development frameworks for the development of mobile apps, in the case where attaining a good UX is a relevant project objective.

All the details of the cross-platform framework selection study are in [Angulo et al., 2014].

2.2. Differences between Native and Cross-Platform Development

Expressing the differences between both concepts in simple words is that native development means that the code is compiled for specific devices and written in different programming languages (Objective-C for iOS and Java for Android). On the other hand, cross-platform development is a solution on which the same source code (usually HTML, JavaScript and CSS) is compiled for multiple platforms.

The native approach offers better performance and grants access to all hardware features available maximizing the capabilities of the device. On the other hand, each OS targeted must have its own specific development process. The disadvantages of this approach are that it requires more development time (as the version for each platform has to be developed from scratch); the projects are more expensive and require more resources.

Cross-platform solutions allow building the app on different platforms once the main code is completed, saving resources throughout the development process. The downside of cross-platform solution is that implies a few limitations while accessing to the hardware features, it implies writing some specific code to adapt to each platform as detailed below, it depends on APIs or modules to connect and access to native features, and may have worst performance figures. We aim to find in this work if there is also some loss in terms if user experience.

There are different options and frameworks in the market that allow developers to enter into the cross-platform development world. Depending on the cross-platform framework selected, the development would work with different technologies; some solutions will compile the code into native app but some other ones use web views and APIs or modules to connect with native features.

It should be highlighted that the cross-platform approach does not mean that the same code works automatically for all the different platforms or different devices. Most of the code can be reused, but it also requires some degree of customization in most cases. Moreover, depending on the framework that is used and on the nature of the application, some particular features or functionalities should be programmed specifically for a determined platform or environment.
Table 2.2 shows the differences between the technologies for developing apps based on a comparison done by Naga Harish [Harish, 2013].

Table 2.2: Comparison between native, cross-platform and HTML5.

<table>
<thead>
<tr>
<th></th>
<th>Device Access</th>
<th>Speed</th>
<th>Development Cost</th>
<th>Approval Access</th>
<th>Code Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTML5</td>
<td>Partial</td>
<td>Good</td>
<td>Reasonable</td>
<td>No need</td>
<td>One</td>
</tr>
<tr>
<td>Cross-platform</td>
<td>Full</td>
<td>Better</td>
<td>Reasonable</td>
<td>Mandatory</td>
<td>One</td>
</tr>
<tr>
<td>Native</td>
<td>Full</td>
<td>Best</td>
<td>Expensive</td>
<td>Mandatory</td>
<td>Different</td>
</tr>
</tbody>
</table>

2.3. Usability

Jakob Nielsen defines usability as “a quality attribute that assesses how easy user interfaces are to use. The word ‘usability’ also refers to methods for improving ease-of-use during the design process” [Nielsen, 2012a]. The International Organization for Standardization (ISO) defines usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” [ISO, 1998].

Nielsen in his book *Usability Engineering* describes usability as a property of user interfaces composed by multiple components as: learnability, efficiency, memorability, errors and satisfaction. Those attributes are described as follows [Nielsen, 1993]:

- **Learnability**: The system should be easy to learn and should be simple to understand to start working with it as soon as possible.
- **Efficiency**: The system should be efficient to use and when the user learns it a high level of productivity can be obtained.
- **Memorability**: The system and its steps should be easy to remember to allow the user to return to the system and being able to use it without learning everything again.
- **Errors**: The system should have a low error rate. Catastrophic errors must not occur.
- **Satisfaction**: The system should be pleasant to use. The users must be satisfied when using the system.

The international standard ISO 9124-11[ISO, 1998] also mentions that these attributes\(^1\) are affected by the following factors:

- **Users**: Characteristics of who is using the product and their level of knowledge about the software or the technology. Importance of specific and trained users.

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\(^1\) The attributes mentioned by Nielsen on his definition of Usability.
• **Goals:** The actions that the users are trying to perform with the product. Do the product and the users have the same goals?

• **Context of use:** The environment on which the product is being used. The software or the application must be designed for the specific environment on which it will be used.

Usability is usually measured by doing a study where a determined number of participants try to complete and perform certain specified tasks [Nielsen, 1993]. Depending on the nature of the application or the software, the usability measures may vary. The set of usability measures are required because as it is known, users are different. Therefore, the usability study must have a defined scope and specification for being able to determine the usability level of the application and the next steps required to improve it.

**Importance of Usability on Mobile Devices**

According to Nielsen [Nielsen, 2012a], "usability is a necessary condition for survival" because if an application is difficult to use, the users will leave and probably never return to it; this is especially true in mobile applications. Nowadays, users have access to many kinds of apps or software that performs the same task. If one specific application is difficult to use or complex to understand, the users will simply uninstall it and look for another solution.

On the mobile application world, users will not tolerate apps that are slow or require a lot of time to load the information. Speed is very important because users usually have just a few minutes to actually use the application; in fact, efficiency is even more important for mobile apps than for websites on computers.

Having simple\(^2\), organized and functional applications can engage and attract more users as well as maintain a constant user population. The available space to present information in a mobile app is reduced; therefore, the users must not be overwhelmed with too many choices or distractions, apps must have a linear design offering clear options to perform certain tasks.

Context of use is important, since it is more varied than in desktop computing and it has more constraints as smaller screens, locations, reduced data plans, fat fingers, etc. The mobile applications have to be efficient and with high performance to engage users and their design must consider the mobile context constrains in order to obtain a high usability level and a good interaction.

Usability is a key aspect on the development of mobile applications and can be the main reason of the success or failure of a specific project. There are several factors that are relevant and important for generating a great user experience and for allowing a fluid and smooth interaction between the users and the software. The impact of all those factors should be tested and measured to ensure a successful user experience while interacting with the software.

Measuring usability is actually analyzing the usefulness of software from the user’s point of view. Usability testing usually involves a certain amount of users, performing pre-defined tasks under specific conditions or environment. The users can be divided

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\(^2\) Simple in this case does not mean that there is a lack of functionality. It means that is simple to understand, the functionalities are clearly specified as well as the options for the user.
according their experience or to some specific characteristic. Depending on the nature of the experiment or the nature of the project the number of users may vary as well as the participants' selection process. The feedback obtained is collected by different methods and later used to improve the application, correct possible mistakes or find out the nature of errors.

2.4. User experience in mobile applications

Jakob Nielsen and Don Norman said “User experience encompasses all aspects of the end-user's interaction with the company, its services, and its products” [Nielsen, 2012b]. Furthermore, user experience is defined by ISO as "a person's perceptions and responses that result from the use or anticipated use of a product, system or service" [ISO, 2009].

A great user experience is meeting the needs of the customers in a fluid and simple way generating the feeling of joy to use a determined product. Multiple disciplines and concepts have to be merged and taken into account for providing an exemplary interaction between the users and the application.

User's preferences, behaviors and reactions must be considered when designing and implementing the interaction on a mobile application.

Usability and user experience are fundamental aspects to be taken into account in a mobile application development process. Having an application that offers a great user experience and is simple to understand and to use can be a total success. The main idea is to provide the best user experience possible in order to engage the users with the application and facilitate the interaction and usage of the app.

The problem arises when a frequent user of specific mobile platforms finds out that a specific application works in a completely different way of what he/she expected and is used to. If the expectations are not met, the user can feel frustrated and even stop using the application.

The mobile user experience is totally different than the user experience in traditional desktop applications. According to David [David, 2011], several features of the mobile devices have influences and affects on the final interaction between the users and the mobile application. Those factors are the differences in screen size, portrait/landscape and input devices, among others.

Labrecque [Labrecque, 2011] states that some factors and paradigms must be taken into account at the moment of designing and developing the interaction on a mobile application. These factors are:

- Screen paradigm or how to manage the different screens of the app and the navigation throughout them.
- The hardware, it is not the same for all platforms and some options or actions do not behave and react in the same way.
- Gestures, the UI design and the interaction need to consider the usage of gestures in order to make easier the interaction between the user and the app.

Both iOS and Android have their own interface guidelines to consider when developing a native application. These guidelines have many differences and that fact must be
considered at the moment of developing a cross-platform application [Apple, 2014b] [Google, 2014].

There are three main approaches to address this subject. The first one is providing the same behavior and the look and feel according to the platform on which the application is running. The second one is having the same styles and the same look and feel on the application for all the platforms. And the third one is delivering an application with the same look and feel but customized to follow the specific guidelines for each targeted platform [Barea et al, 2013].

The following paragraphs describe in detail each interaction design approach from a cross-platform development framework point of view.

2.4.1. Platform dependent

Platform dependent approach consists on generating a different interaction for each targeted platform, following the platform guidelines and philosophy [Barea et al, 2013].

For adapting this approach to the cross-platform development frameworks world, most of the solutions are based on style sheets (CSS) and images that have to be added to the application to generate the look and feel similar to a native app on each platform. To be able to use this kind of solutions, it is necessary to detect the device's platform in order to include the correct files and pieces of code to change how the application looks.

It is important to mention that not all the styles have to be created by the development team. In the market there are UI frameworks and libraries that contain the mobile platform styles and can give the desired look and feel. This solution can bring benefits to the users (giving them the expected behavior) and the developers (facilitating the development process).

2.4.2. Own cross-platform

This approach aims to keep the same styles and interaction on the application regardless of the targeted platform. The user experience is coherent between the targeted platforms. On the other hand, platform conventions are not followed; the application defines its own behavior and interaction flow [Barea et al, 2013].

This solution can benefit the development process as the styles have to be done just one time. As a downside, this approach can cause an unnatural behavior for the users. For example, the buttons are in other places or have different shapes from the rest of the apps in the platform.

In this case, some UI libraries can be used or the development team can create the styles and interactions by themselves providing a new solution. The key aspect is the nature of the project and the usability level desired.

2.4.3. Adapted cross-platform

This approach is a mixture between the two previous approaches; it proposes the final product as an application with similar appearance but its interaction design follows the targeted platform conventions [Barea et al, 2013].
The user experience is better adapted for each platform meanwhile offering coherence and similarities between platforms. The downside of the approach is that some “special” features available only on one platform must be left behind [Barea et al, 2013].

In a cross-platform development framework, the approach would be creating specific look and feel and styles to maintain coherence between platforms but keeping in mind the consideration of each platform. The usage of UI style libraries or plugins probably can be helpful to follow the platform conventions as those libraries can be applied to each platform separately.

2.5. Bibliographic research on usability evaluation of native vs. cross-platform applications

As the mobile application development is relatively new as well as the development of mobile applications with cross-platform frameworks, there are not many studies that compare the usability between native and cross-platform versions of an application in terms of usability.

The objectives of the bibliographic research are to identify the studies published on the subject of the present work, and identify their methodological approach to usability evaluation of different versions of the same mobile application.

The research targeted also the effect of using cross-platform frameworks in the user experience of mobile application; that means evaluating the reactions of the users and their performance while using two versions of the same application, one developed with cross-platform framework and the other without them.

As the technology is changing very fast and older smartphones user experience cannot be compared to recent ones; the first iPhone was released on 2007 and the first Android on 2008 and the development of mobile application has increased a lot and the development methods have changed. Therefore, the research is focused only on studies and information generated from 2010 until 2013. In the following paragraphs, each bibliographical reference is analyzed providing a summary of the publication and the valuable information for a usability study to compare native vs. cross-platform applications.

2.5.1. My App is an Experiment: Experience from User Studies in Mobile App Stores

2.5.1.1. Summary

This article is about the performance of user purchasing and using apps that are available in Google’s Android Market (currently known as Google Play) and in Apple’s App Store. Also, it is focused on user behavior inside each store [Henze et al, 2011].

The study was performed using five different applications of different kinds trying to test off-screen visualizations and the touch performance. These applications were formal ones (navigators or map explorers) or some informal ones (games) in order to prove different reactions of the users.
There was a test on the reactions of the users about allowing the researching team to use their data; in all the applications they used different approaches to address this topic with two approaches:

- Explicitly asking for permission at the beginning.
- After several hours of use ask for permission of obtaining data or recording data since the beginning.

The results and the reactions of the users were different depending on the approach used. The most successful one was asking at the beginning because more data was obtained.

As the experiment was about the usage of stores, the applications were offered in the stores and the users downloaded them freely on their own devices. As a result the tests were performed in a real and natural environment and the user had his/her own device, without any adaptation period.

The researchers performed experiments, quasi experiments and observation with the different applications based on the idea “that Apps distributed to thousands of users can successfully be used as an apparatus for controlled experiments” [Henze et al, 2011].

As a conclusion about the validity of the data obtained from the different experiments, the authors mentioned: “we found that the design of the experiment and the unpredictability of the usage are the two biggest threats to the internal validity” [Henze et al, 2011].

2.5.1.2. Valuable Information for the usability experiment

“In the lab the experimenter can make sure that the participant conducts the task as scheduled. If conducting experiments in an application store, the experimenter has no control over how the task is conducted” [Henze et al, 2011]. According to the authors of this work for the purposes of cross-platform usability study, tests should be performed in a controlled environment.

Regarding the feedback generated of the usage of the application, the authors observed that collecting the data directly from the beginning provides more information but it has to be analyzed and refined.

On the other hand, the researchers must be aware that users can leave the application running and not performing any task or perform the task in a different form as planned. “The unsupervised use of the apps offers many opportunities for unforeseen usage” [Henze et al, 2011].

The authors’ claim that obtaining feedback from other channels, such as emails or feedback comments, can provide good information but mostly they generate SPAM, therefore the usage of these methods is labeled as not always good. However, they promote the usage of incentives in order to catch the user’s attention to perform a valid evaluation or a valid feedback³.

³ Valid feedback is defined as non-SPAM
2.5.2. Usability of mobile applications: literature review and rationale for a new usability model

2.5.2.1. Summary

This paper is a literature review about the usability issues related to mobile applications and a usability model that can be used to assess usability [Harrison et al, 2013].

The authors establish first a description of concepts related to Usability attributes described by Nielsen in his book *Usability Engineering* [Nielsen, 1993], which are Efficiency, Satisfaction, Learnability, Memorability, and Errors. Additionally, the authors define the usability attributes established by ISO as background basic information. All this information has to be adapted to the “mobile world”; this means, that some limitations have to be considered.

After developing all the background, it is proposed the usage of PACMAD (People At the Centre of Mobile Application Development) usability model which according to the authors “was designed to address the limitations of existing usability models when applied to mobile devices” [Harrison et al, 2013]. In other words, this adaptation of the model combines the classical attributes with the considerations of mobile devices such as mobility and different context of use that may affect the interaction between the user and the application.

The paper describes the entire PACMAD model, its factors and attributes explaining the impact that each one has and mentions the level of importance of each factor to obtain a successful usability of a mobile application.

In order to evaluate the appropriateness of the PACMAD usability model in mobile applications, the authors performed a literature review focusing on papers between 2008 and 2010, which had the evaluation of a mobile application [Harrison et al, 2013].

The results of the literature review revealed which attributes are the most important and have to be considered on the PACMAD usability model allowing to a discussion about the importance of each attribute and how did the previous studies have managed them.

As conclusions, the authors said, “The prominent models of usability do not adequately capture the complexities of interacting with applications on a mobile platform. For this reason, this paper presents our PACMAD usability model which augments existing usability models within the context of mobile applications” [Harrison et al, 2013].

2.5.2.2. Valuable Information for the usability experiment

This paper provides the literature information and description of the PACMAD usability model, which can be helpful in order to focus the experiment on proving the most important attributes for mobile apps. Also it may allow the evaluators to establish a comparison between the cross-platform and the native versions of the application.

This paper also shows the results found on the previous studies used for the literature review and how which attributes were more considered in the evaluation process. This information helps to create some tests that consider all attributes and also to consider

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4 Papers reviewed by the authors of this research [Harrison et al, 2013].
the effects of those attributes for being able to compare both versions of the application.

There is an interesting discussion about the factors Context of use and User, which in most of the documents analyzed by the authors “were considered in less than 10% of the papers” [Harrison et al, 2013]. In fact, those attributes are very important because they affect directly to the usability level of an application and also to the usage time of the application. In simple words, if the user is not able to perform what he/she wants easily probably will not use the application so often.

From this paper it can be extracted the definition of terms and attributes for establishing the literature and the background information for the experiment.

### 2.5.3. How to Improve User Experience in Mobile Social Networking: A User-Centered Study with Turkish Mobile Social Network Site Users

#### 2.5.3.1. Summary

This paper is about the effects that design aspects in the user interface and how the usage of different mobile devices can affect the user experience in social network sites [Öztürk et al, 2011].

This experiment was conducted in Turkey under controlled circumstances with 25 university students. The tests were performed using iPhone and Blackberry devices.

In this case the analysis is performed on social network sites and the corresponding mobile application. The case study was Facebook. The authors compared the usage and the problems found by the users when performing a certain list of tasks on their mobile phones. It is remarkable that study subjects had previous experience using Social Network Systems (SNS).

The authors were also interested on proving the following hypothesis: “User experience in mobile platforms appears to be one of the most promising topics of research in the area of human-computer interaction, as people suffer from usability issues caused by the design of mobile interfaces and limitations of the mobile devices” [Öztürk et al, 2011].

Methodologically, the study was proposed in two study lines:

- The affection level of the design aspects in the graphical user interface of the mobile app on the mobile user experience in SNS.

- The affection level of the capabilities and constraints of the mobile devices on the mobile user experience in SNS.

Under these two lines, the participants were asked to perform some different tasks in established times using one of the mobile devices available (iPhone or Blackberry). The experiment was performed in a facility where all the interactions and navigations could be recorded by the observers.

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5 Native and Cross-platform versions.
In this study, the authors decided to use an “analysis framework derived from the study of Wroblevski and Nielsen and Norman” [Öztürk et al, 2011]. “The analysis framework that was derived from these two studies includes the following parameters: Visibility and Scalability, Consistency and Standards, Discoverability and Feedback, Reliability, User Diversity, Bandwidth and Speed in Mobile Network Performance, Awareness and Use of the Capabilities in Mobile Phones” [Öztürk et al, 2011].

Each of the attributes mentioned on the analysis framework is explained showing its pros and cons establishing the facts that caused good impressions or troubles to the users while performing the required tasks.

2.5.3.2. Valuable Information for the usability experiment

In this case, the valuable information is the attributes mentioned in the analysis framework as the main conditions to establish a comparison in terms of usability between an application and its original web version. As the application that will be used for our usability experiment shows some information extracted from the official website of the School of Computer Science at UPM, these attributes could be considered if the aim was to evaluate the correspondence and the usability of the application compared to the webpage.

This study also compares two different technologies that could also be useful in order to implement our study. Probably some ideas could be obtained to establish the comparison of two different technologies.

2.5.4. MuZeeker: Adapting a Music Search Engine for Mobile Phones

2.5.4.1. Summary

This paper is about the usability test between a mobile application and its corresponding web-based application. The authors describe MuZeeker as “a search engine with domain knowledge based on Wikipedia” [Larsen et al, 2010]. The main discussion is the work required to adapt the web-based application into a usable mobile application that allows the users to perform the same kind of work in both applications.

The entire application is described showing the main algorithms and the main components of it. This work details the different user interfaces and its components for the web-based and the mobile applications. As the paper is related to the creation of the mobile application, this interface (mobile) is more deeply described in technical and usability terms.

In order to prove the usability and that both applications allow the users to perform the same kind of searches and provide the same amount of information an experiment was performed. “Usability evaluations of the web-based and mobile MuZeeker user interfaces have been carried out with the primary goal to compare and contrast to a well-established search engine, here chosen to be Google” [Larsen et al, 2010].

After performing the experiment, the authors found out that some features of the application were more used than others. Also as the web-based application can provide more information at one glance (due to screen size reasons) the information and functionalities provided in the mobile applications should be the most representative.
Another conclusion of the experiment is that “the mobile MuZeeker application demonstrated the search approach as a promising way to make large quantities of information searchable on mobile devices” [Larsen et al, 2010].

2.5.4.2. Valuable Information for the usability experiment

The information obtained in this paper that can be useful for the usability experiment is how the research team has performed the experiment and evaluated the performance of the experiment’s tasks. Also the attributes that they evaluated at some point can be a background to consider for the particular case of a usability experiment.

The comparison of both points of view (web-based and mobile versions) can be used for establishing additional parameters to perform the evaluation, and when defining user’s task to look for some specific information.

2.5.5. Oh App, Where Art Thou? On App Launching Habits of Smartphone Users

2.5.5.1. Summary

The paper describes the study of app launchers on smartphones to investigate the habits of the users at the moment of launching the mobile applications of their phones. “Users in our study tended to sort apps based on frequency of use, putting the most frequently used apps in places that they considered fastest to reach” [Hang et al, 2013]. Also, “users start most apps from within other apps, followed by the use of the home screen” [Hang et al, 2013].

Based on previous studies of usability, the authors mention different factors that can affect the performance of tasks according to the user’s age and their way of thinking. As one of the goals of the experiments was finding how the users start their applications, a special way for recording data was required. “Therefore, we developed an Android application collecting information on the locations from which apps are launched” [Hang et al, 2013].

“The main contribution of this work is to provide the first insights on how users utilize launching concepts on current smartphones, why they use them and to reveal areas for refinement” [Hang et al, 2013].

The experiment of this paper is based on Android devices but the same concepts can be applied to iOS or to Windows mobile, as mentioned by the authors. Before performing the study, a preliminary study was handled in order to test the study conditions and the reliability of the app. One interesting point is that the users who were part of the experiment were using their own smartphones. These conditions decreased the adaptation time and they also guaranteed that the data was recorded under real-world conditions.

The results of the study show the different habits of people at the moment of launching their applications and how they organize them depending on different factors. Additionally, this research and its experiment show some kinds of behaviors as different factors were measured and analyzed (launching behavior, navigation time, home screen arrangement, among others).
2.5.5.2. Valuable Information for our experiment

This paper provides information about the performance of a usability study and user behavior about certain conditions; in this case, it is about how different users launch the applications on their smartphones. It also contains different aspects that should be considered during the evaluation on a study about users’ behavior.

The study provides also good ideas about the previous preparation required for an experiment and also about the procedure for long-term studies. It is also interesting the establishment of the conditions; this means, the election of the target users, the conditions about how the study should be performed.

It was realized on real-world conditions, therefore it provides good parameters or considerations required in order to record data and to facilitate the users’ job at the moment of performing the required tasks.

The results also show the cons about performing a real-world experiment, as the authors were not able to analyze the data of all the participants for several reasons. This information can be useful at the moment of deciding between a controlled environment and a real-world environment for the evaluation.

2.5.6. Does size matter? : Investigating the impact of mobile phone screen size on users’ perceived usability, effectiveness and efficiency.

2.5.6.1. Summary

This paper is about the “impact of mobile phone screen size on users’ effectiveness, efficiency and perceived usability” [Raptis et al, 2013]. These conditions were measured using the System Usability Scale SUS. The experiment was about the usage of an information seeking application used in different mobile phones with different screen sizes.

The experiment has as background the wide variety of mobile phones screen sizes that are on the market in these days. As one of the first steps, the authors have to select representative screen sizes on different mobile phones in order to be able to perform an experiment under similar condition but changing the size of the screens.

As a result of this premise, they picked 3 different Samsung phones, which provide different screens but the usage is very similar. “The fact that Samsung TM offered phones that had different screen sizes, but the same materials used for the casing, both in front and the back, same physical buttons, almost the same appearance, same colors and similar age, constituted Samsung TM as an ideal candidate” [Raptis et al, 2013].

The authors tried to provide as much similarities as possible between the 3 devices, therefore the installed versions of the app launcher, the application itself and some other components that may have influence had the same version on all phones.

The paper explains the measurement factors and instruments used to record and obtain information and the process required to evaluate them explained as variables or factors that the authors considered relevant for their investigation. The authors present
several statistical values and information in order to generate some usable data to prove the hypothesis.

A discussion based on the results found on the research is also provided and it shows the different points of view as well as the role played by the screen size during the performance of the testing activities.

One of the conclusions of this study is as follows: “Mobile users that interact with a device with the purpose of mainly performing information seeking tasks, such as Internet browsing, will be more efficient if they use a device with a screen larger than 4.3 inches” [Raptis et al, 2013]. According to the authors, “findings do show that screen size matters” [Raptis et al, 2013] at the moment of thinking on everyday users and efficiency while they perform their everyday activities; the user experience can be affected.

2.5.6.2. Valuable Information for the usability experiment

This paper provides valuable information about the experiment itself and the measurements recorded and analyzed. The procedure and the selection of tasks is very clear as well as the measures required to be able to prove the authors' hypothesis.

If the idea is measure usability, some parameters have to be considered and most of the studies provide information about them in order to evaluate the usability of an application. However, there are few studies about the physical characteristics of a mobile phone and its direct impact on usability as the ones showed in this study.

One of the measurement instruments was the SUS questionnaire as explained by the authors: “The reasons for choosing SUS were the facts that it is free, very simple and short (10 items on a 5-point scale) and more importantly that it has been found remarkably robust on various studies.” [Raptis et al, 2013]. Therefore, its use can be considered on our study.

Another conclusion of interest is that “researchers that measure perceived usability through SUS will not observe any differences if they evaluate an application on devices with different screen sizes.” [Raptis et al, 2013].

2.5.7. Carim: the experiment

2.5.7.1. Summary

This is an experiment which objective is to test the usability of a testing application under different circumstances and versions. The application is a game about a lunar module and the user has to be able to park it on the parking spot in the moon using the brakes and turning it to right or left [Mateo, 2013].

There are two versions of the app with a modification in the user controls:

- **Version 1**: The first version works entirely with the mobile device; this means that the user must rotate the smartphone in order to move the lunar module and try to arrive to the parking spot. In order to apply the brake, the user has to tap over the lunar module.
Version 2: The second version of the application has the same purpose but it provides the user a control panel. The control panel is composed by three buttons (brake button, left and right arrows), which allow the user to move the lunar module and to accomplish the goal of the game.

Before playing, the user has to complete several questions that establish the environment on which the application is being used. Then the users have to select the difficulty level and play the game. The game provides as many attempts as users want when they decide to finish the game, there is a final questionnaire which evaluates the experience of the user and his/her thoughts about introducing mobile technology into their daily activities.

2.5.7.2. Valuable Information for our experiment

From this experiment, future usability experiments can use some of the metrics or questions that they used to establish the user’s background and a couple of the questions from the satisfaction survey.

It can be also interesting the information about how the researcher logs the data from the application usage.

Some of the questions that can be used in order to measure different factors after the usage of the apps are:

- Which device is being used? Smartphone, music player (iPod) or tablet
- Which is the mood or which are feelings of the user after using the apps? → giving 5 options from very happy to very unhappy for example
- How pleasant was the experience of using the apps? → Rate from 1 to 5 or form 1 to 7.
- Rate the practical experience of the apps? → Rate from 1 to 5 or form 1 to 7.
- Rate how predictable are the apps? → Rate from 1 to 5 or form 1 to 7.
- Rate how structured are the apps? → Rate from 1 to 5 or form 1 to 7.
- Rate how simple to use are the apps? → rate from 1 to 5 or form 1 to 7.
- Rate how captivating are the apps? → Rate from 1 to 5 or form 1 to 7.
- Which form of consulting is more productive the app or the website of the school? → Rate from 1 to 5 or form 1 to 7.

These questions can be included on the questionnaire provided to the users during the experiment or after the experiment in order to establish the personal perception of the users about the experience with the apps.
2.5.8. Developing Mobile Apps Using Cross-Platform Frameworks: A Case Study

2.5.8.1. Summary

This paper is about a study performed in order to determine whether the users are more comfortable and adapt better to a native version of an application or to a version created with a cross-platform framework [Humayoun et al., 2013].

It shows the problematic of having many different mobile devices and mobile OS and how this aspect is a challenge for the development teams and the companies in order to be able to produce great apps for all the markets. “Developing mobile apps separately for each platform or device is costly and time consuming process while keeping focus on just one platform or device reduces the number of accessible users” [Humayoun et al., 2013].

The study focuses on the development of the apps and the problems that occurred while trying to replicate the same functionality in different circumstances and different working environments. Three different scenarios were selected with three different goals for the apps. All the apps for each case had to be developed for iOS and Android, the apps were developed as native apps and also using the cross-platform frameworks selected previously by the researchers.

After generating the different apps, a user evaluation study was done with 9 participants in a controlled environment. The main goal of the user study was to determine the “right” environment to develop. The results were evaluated to determine which version was the best one on each of the three scenarios. During these evaluations the performance of the app was also considered.

Another evaluation performed as part of this study was the development process of the scenarios against software quality metrics to determine the existing differences between the platforms and frameworks used. As part of the results found, some troubles with OS’s versions are mentioned as well as some problems at the moment of implementing a specific feature for a determined platform or framework.

The conclusions of this study are that “in many terms the results of cross-platform frameworks are as good as the native ones and in some cases even better” [Humayoun et al., 2013]. “Overall, it can be said that the hybrid cross-platform frameworks are a good alternative to the native implementations with definite better cost-efficiency” [Humayoun et al., 2013].

“In the cases where the interaction response time plays an important role, if the quick response is not very critical then cross-platform development could be the alternative option; otherwise, the native platforms are slightly better than the cross-platform frameworks. This is because the native implementation environments provide better solutions for the critical interaction response, which enhances the user satisfaction level” [Humayoun et al., 2013].

In the future, the options provided for cross-platform frameworks will be better and extended which will benefit the development process of mobile apps adapted for different markets.
2.5.8.2. Valuable Information for the usability experiment

In this case, it is remarkable how the researchers handled the user study. The users were divided according to their knowledge about interacting and working with smartphones and mobile devices. Also the considerations and how they collected the information of the users with questionnaires and the testing process which was testing all the available versions of one scenario and then each user had to select the best version according to them for keep using the same app in the future.

The interaction-response of the different versions of each scenario was measured by the users in a scale of 1 to 5 according to their overall satisfaction. The main idea is that the users can test several versions of the same app to compare the usability degree of the products developed on native or on cross-platform framework environments.

The general information described on this paper can be used as a background for a future usability experiment and it can be the baseline from which the experiment can be generated. The results can be also considered at the moment of comparing the results that will be obtained in another experiment which address the same topic. This means comparing the performance of native and cross-platform versions of the same app for recording and analyzing the reactions of the users.

2.5.9. Native versus Cross-platform frameworks for mobile application development

2.5.9.1. Summary

This paper compares both approaches for developing mobile applications: native and cross-platform. The authors describe each of the approaches and do an introduction of each one. Later, a comparison is presented; it is based on specific parameters as UI user experience, performance, device-specific features, distribution via app-store, multiple platforms deploying costs, developers support, security, time access to new OS inventions, code reusability, design challenges and availability of programming expertise. In the third section, the usage of Eclipse as a tool for developing mobile applications is analyzed.

The native vs. cross-platform debate arises as a consequence of the proliferation of development environments for the mobile application world. To develop mobile applications, developers can chose one of the mentioned approaches to target a specific platform or being able to run the application across multiple devices and platforms [Madaudo et al., 2013]. The authors present the available development environments and their advantages or disadvantages when using them as a part of a development process.

The comparison addresses the technologies used and how they are used to develop mobile applications describing the programming language, the runtime environment and they way the application is generated either inside a WebView or as a native application. The first solution uses a browser screen within a native application which renders HTML5, JavaScript and CSS. The second one uses native classes and objects obtained after compiling a scripted language on which the application was developed [Madaudo et al., 2013].

The information presented suggests that after comparing native vs. cross-platform development environments using the parameters mentioned above, the native
environments are better than the cross-platform as the latter excel only on three topics: code reusability, design challenges and availability of programming expertise [Madaudo et al., 2013].

The authors mention the availability to integrate the frameworks to common integrated development environments (IDE) like Eclipse. They mention the possibility to use plugins or complements to perform this integration. Their idea is to provide information about the needs and requirements to integrate an IDE and a framework “to make the mobile application development as productive and manageable as desktop and web development have been for long” [Madaudo et al., 2013].

**2.5.9.2. Valuable Information for the usability experiment**

The information provided by the authors is useful to set a baseline for the cross-platform framework analysis and selection process as well as to determine which option suits better to our proposes. Several frameworks are described, their technologies and some benefits are mentioned which is helpful as background information before researching each one in depth.

Even though a comparison between native and cross-platform approaches is stated, this paper only shows the position of the authors. There was no user testing process or an experiment that supports the results. But this information can be used to set the baseline for our experiment and have in mind some considerations regarding both approaches as the authors conclude that both approaches are complementary.

Some topics mentioned on the paper as the security, the design challenges and the code reusability are helpful to plan the prototype development process taking into account the advantages and disadvantages of the cross-platform frameworks in these subjects.

**2.5.10. Conclusions of the bibliographic research**

- The validity of the data obtained from the different experiments can be less predictable if the users are allowed to test the app in a real environment. In other words, if the testing process is not performed in a controlled environment and under controlled conditions, the accuracy of the data could not be trusted 100% due to several reasons. For example, the user left the app running but is not actually using it, etc.

  There are several threats that must be considered while analyzing the data obtained from this kind of experimental processes [Henze et al, 2011].

- On the other hand, using a real environment for testing the applications can bring many benefits as being able to analyze the real habits and actions of the users interacting with an app outside of laboratory boundaries. Selecting this kind of experiments can generate “extra” information produced by the exploration realized by users on their own, not only doing some defined tasks, otherwise exploring the app or trying to use other features not considered on the defined tasks [Henze et al, 2011].

- Performing the usability test and analyzing the user experience in different contexts of use can provide valuable information to understand the possible problems or difficulties that users may have while performing a specific task. Analyzing different environments can determine if the problem is located on a
specific technology or device [Larsen et al, 2010] [Henze et al, 2011] [Öztürk et al, 2011].

- Usability evaluation models should be customized for addressing the mobile approach. Some criteria have to be modified in order to be able to analyze the user experience and the interaction of a mobile application. For instance, factors as Context of use and User have to be considered in a different form as they affect directly to the usability level of a mobile application [Harrison et al, 2013].

- Using an established model can be helpful for setting a baseline to be able to compare two versions of the same application, the native and the cross-platform versions, in order to be able to create different tests and set a point of view to compare the performance and user experience of both versions [Harrison et al, 2013].

- The different kinds of mobile devices available now in the market and the characteristics that each one of them has can affect the usability and the effectiveness of a user while performing a specific task. One of the most important factors is the screen, if more information or controls are visually available, the completion of tasks can be faster or more understandable than in small devices. [Raptis et al, 2013]

- Another approach for testing the usability of an application would be creating two different versions and adding or modifying the graphical interface or the functionality to compare the reactions of the users against the changes or the modifications. These actions can settle a pattern to be able to determine which one would be the best approach for a specific application. [Mateo, 2013]

- The decision to use a cross-platform development framework or developing native code directly is not an easy one. [Madaudo et al., 2013] compare both approaches, stating that native apps provide better UX, by means of more fluid and responsive UIs, because cross-platform frameworks may not offer access to the full device APIs (Application Programming Interfaces). Their work is just a position paper based on the experience of the authors, without experimental validation.

- [Humayoun et al., 2013] evaluate three cross-platform development frameworks with the development of three apps where the interaction is based in touch events (including gestures) and they access the device hardware (such as the accelerometer or the camera), and the file system.

Not all three apps were developed with the three frameworks. From an interaction point of view, the three apps are quite basic in terms of navigation, since they just have one or two screens, despite being navigation one of the main differences in interaction style between platforms.

A user evaluation study was performed in a controlled environment with 9 users, of which 3 were Android expert users, and 3 were iOS expert users. Test participants were asked to evaluate app response time and to grade their satisfaction in a 1-5 scale; and the results show a higher user preference for the native versions, but in two of the three scenarios with little difference. The results of this work are interesting as a first approximation to the problem at hand, but they are difficult to extrapolate to more complex applications, because...
the case studies considered are very basic applications, and the number of participants in the study who are platform-experts is reduced (just 6).

- It is remarkable to mention that any of the research papers found address the topic of comparing the native and the cross-platform approach in terms of usability and UX. Therefore, the proposal of this work is novel and it is an issue to be resolved; the results of this study can generate important information about the users’ perception of an application when it is developed using native or cross-platform approaches.
3. Development of the Application Prototypes

3.1. Introduction

The application used as case study for this research is a mobile application for the School of Computer Science at UPM. This application allows the members of the university community to have access to important information and data of the University from their smartphone without necessarily having to access the official website. The native versions of the application for iOS and Android have been developed by an independent team. On the other hand, for the purposes of this study, a prototype developed with a cross-platform framework has to be done.

As mentioned on the section 2.1, the framework that used is Titanium Appcelerator and the development approach used is User-Center Design (UCD).

On this chapter, the development process is described as well as the framework characteristics and the difficulties found during the development process.

3.2. UCD

User-Center Design is a development approach to design a product or service in which the end-user is placed in the center of the process [usability.gov, 2014]. The main aim is to generate the satisfaction of the end-users of the product by involving them in the design and evaluation of the final product.

The UCD approach should usually be integrated with other development activities. Those activities should be planned and executed during the development of a product [usabilitynet.org, 2006]. UCD seeks to show the real behavior and answer questions about real-users tasks and goals; based on these findings, the design and the development has to be improved for being able to generate a better version of the final product which facilitates the user to complete certain tasks.

According to Don Norman [Norman, 1990] the UCD is a philosophy based on the interests and needs of the users making special emphasis on having understandable and usable products.

Based on Norman [Norman, 1990], Sharp, Rogers and Preece [Sharp et al., 2006], and the website UsabilityNet [usabilitynet.org, 2006], the principles on which UCD is based are:

- Explicit understanding of users, tasks and environments.
- Make things visible and easy to determine the possible actions that can be done by a user.
- Incorporate the user feedback to refine the requirements and the design.
- User involvement on the evaluation of the design.
- Integrate UCD into the development activities.
- Iterative process of design evaluation by users.

When UCD principles are incorporated to the development process of a software product, the information obtained about the beliefs, limitations and needs of real-users should be taken into account and can be helpful to improve the design of the final product in order to optimize the user's experience of a system or a product [Norman, 1990] [Sharp et al., 2006].
Achieving a high usability degree of a product is not a one-time activity; the user interface and the usability of software have to be improved in multiple stages. Usability cannot be isolated from the development context of a product. Moreover, the efforts to improve usability can generate a future return of investment and be part of the success of the product [Nielsen, 1993].

Although the UCD approach interaction with the software development process can be customized according to the organization needs and resources. According to the ISO 13407 standard [ISO, 1999], there are four human-center activities that should be iterated during a project:

- Understand and specify the context of use.
- Specify users and organizations requirements.
- Produce design solutions.
- Evaluate designs against requirements.

The benefits of using a UCD approach are: to generate easy-to-use products, satisfy the end-users, improve the user experience, generate higher initial quality of the system and reduce maintenance costs.

### 3.3. Requirements

All the requirements of the prototype are stated in this section. Following the guidelines of the UCD approach, each functionality is clearly established and described. The application's targets are the students; and the main aim is to allow easy access to relevant information about the university and relative to their studies.

The survey performed the first semester of 2013 to the students of the School of Computer Science at UPM about the most used functionalities of the official School’s website generated a certain amount of functionalities that should be part of the mobile application. Those functionalities were the first implemented on the prototype.

The selected functionalities are summarized on three basic modules compose it. Each module is decomposed and explained in the following paragraphs.

1. **Bulletin Board**: This module allows the users to access to all the information generated by the University as news or announcements which are interesting for the university community.
   
   a. **News**: This functionality allows the users to access to the newsfeed of the school website. In this newsfeed is published information relevant to the university community.

   When the user enters to this sub menu, he/she has a list of the last five pieces of news. When the user scrolls down the table of news and reach the last one, the following set of five pieces of news is loaded and added to the table.

   Each one has its title, a teaser and in the corresponding cases also an image. If the user wants to read more, he/she has to click on the news and a window with all the information is shown.
b. **Adverts:** This functionality shows the adverts and announcements provided by the different departments or services of the university. There are different categories which include specific information about several topics.

The information shown contains a list of the last adverts showing its title, description and date. To obtain more information, each advert should be clicked and a window with its complete information is displayed.

c. **Events:** This option shows the latest coming events that will take place on the School and show the basic information of the event at first glance. Clicking on the event displays the complete event page with all the available information.

d. **Notice:** This option contains the urgent information generated by the school and to be communicated to the students as soon as possible. The notices are shown just for a certain amount of time. The information that is shown is just the title and a short description of each notice.

2. **Staff Directory:** This module allows the users to obtain the contact information of the staff that works at ETSIINF. This module contains information about professors as well as people who work at the different services provided by the University to the students; for example: International Office, Library, etc.

The contact information about the staff that works on the school is grouped according the departments or services where they have their offices. Therefore, it was decided to separate all the available information into departments and services listing all the elements (names of departments or services) from each category.

a. **Departments:** Provides a list of all the available departments of the school. Inside each department, are listed all the people who work there. The names are listed by alphabetical order and by last name.

To obtain specific information about a person, the user should click on the corresponding name and a new window is displayed providing the contact information. Inside the contact information, the user can click on the telephone number to make a call or in the email address to pop-up the email client of the smartphone.

b. **Services:** Provides a list of all the available services of the school. Each service provides a list of all the people who work there. The names are listed by alphabetical order and by last name.

To obtain specific information about a person, the user should click on the corresponding name and a new window is displayed providing the contact information. Inside the contact information, the user can click on the telephone number to make a call or in the email address to pop-up the email client of the smartphone.

3. **Subjects:** This module allows the students to look for specific information of a subject. This information includes: general information of the subject, professors’ information and access to the subject study guide.
This module is organized from the Degrees level; this means that first items listed are all the available degrees of the school. When the user selects a certain degree, all the subjects are loaded and ordered by course.

To access the specific subject information the user has to select a certain subject and then a new window with the general information of the subject is shown. Also there are two buttons for accessing the information of the professors and also the subject guide.

The information of the professors is shown in the same way as the staff information to avoid confusions of the users. Here are also available the functionality to call or send an email by clicking on the corresponding link (phone number or email address).

All these requirements were implemented on the first version of the Titanium prototype. This prototype was evaluated with real users to prove the usability and obtain feedback for being able to improve the final design as described below in section 3.5.

### 3.4. Development of Native Prototypes

The development of the native prototypes was done using each mobile platform programming language (Objective C for iOS and Java for Android). The design and implementation was performed by an independent team. The design and development approach was take advantage of the each platform characteristics increasing the performance of both versions.

The main benefits of using a native approach is that the look and feel of the application as well as the interaction are completely natural for that platform; the developers have easy access to all hardware components as well as to graphical components for the UI.

The prototypes have more than 15 different screens and the information displayed is obtained via web services offered by the university servers and it includes accessing device location services, thus consisting on a full-scale app.

The details of the development process of both native prototypes is out of the scope of this work, therefore, it is not explained in detail. Table 3.1 shows the screenshots of the home screen for the iOS and Android native versions.
Table 3.1: Screenshots of the two native prototype versions.

<table>
<thead>
<tr>
<th>Native iOS version</th>
<th>Native Android version</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Native iOS version" /></td>
<td><img src="image" alt="Native Android version" /></td>
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<td></td>
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</table>

3.5. Development Titanium Appcelerator Prototype

The cross-platform framework used to develop the prototype was Titanium Appcelerator. As it is a cross-platform framework, the main idea was to use UI components that work good on both platforms: Android and iOS. The design and development was oriented to take advantage of the benefits of the cross-platform framework and increase the speed of the development to release working pieces of software for both platforms.

The implementation of the prototype retrieves the information from the university servers via web services and also has access to the device location services and other features. Therefore, the prototype is a full-scale app.

Table 3.2 shows the screenshots of the Titanium prototype for iOS and Android platforms.
Table 3.2: Screenshots of the two Titanium prototype version.

<table>
<thead>
<tr>
<th>Titanium iOS version</th>
<th>Titanium Android version</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Titanium iOS version" /></td>
<td><img src="image2" alt="Titanium Android version" /></td>
</tr>
</tbody>
</table>

In this chapter are explained the characteristics of the cross-platform framework as well as the advantages and problems found during the development process. Finally are stated the results of the first usability evaluation of the cross-platform framework.

### 3.5.1. Characteristics of Titanium Appcelerator

Titanium Appcelerator is an open-source framework that allows the creation and development of mobile applications. The applications are coded on a single JavaScript codebase and can be compiled to generate working applications different mobile platforms like: Android, iOS, Windows Phone, Blackberry OS and Tizen [Titanium, 2014a].

"Titanium Mobile applications are run against a standalone JavaScript engine which invokes native APIs" [Titanium, 2014a]. In other words, the application is written in JavaScript but is generated as a native application.

As mentioned above, the main programming language is JavaScript, which allows the developers to have the same codebase, and being able to develop for more than one platform at the same time. Everything is programmed in the same codebase but at the moment of render the UI components adopt the native look and feel. However, the controls and the events have to be programmed "by hand" into the views. In other words, when a button is added to a window, it is a system button (neither iOS nor Android button). This button adopts the native look and feel and behavior when the application is compiled and runs in a specific platform.

Titanium Appcelerator has different modes for developing a mobile application: HTML5, Classic mode (JavaScript) and Alloy mode (which follows MVC architecture). The classic mode does not separate the different layers of the application having large
amount of code on which the view elements and the business logic are mixed. On the other hand, the Alloy mode includes the MVC architecture adding a clear separation between the project’s layers and improves the scalability of the application.

For the development of the prototype, the development mode used was Alloy mode because it seemed the best option and the one that will generate a more organized and clean source code; it provides more freedom and flexibility at the moment of develop the project and to separate the logic from the presentation layer. It also allows the creation of modular components improving maintainability and reusability of the code.

The Alloy mode provides organization to the different components of the application making the code easier to read, manage and re-use. This mode uses XML files and TSS files (styles) to manage the view, the business logic and the models are managed on JavaScript files. The MVC framework is based on Node.js with Backbone.js and Underscore.js support. All these libraries allow a better management and facilitate the coding process providing access to extra functionality [Titanium, 2014b].

3.5.2. Advantages identified in Titanium Appcelerator

During the development process of the case study, some advantages and benefits of the usage of the framework were identified. These characteristics helped the development process and contribute to generate a working prototype. The following list contains the identified advantages:

- One benefit of using Titanium according to Appcelerator (the company which distributes the framework) is that the application build is generated with a native look, feel and performance having a good integration with the native ecosystem of each mobile platform [Titanium, 2014a]. For the author of this work, this advantage contributes a lot for being able to generate a good UX and help the developer to adapt their final product to each mobile platform targeted; the framework automatically adapts some components to the mobile platform conventions producing a native look and feel.

- Generating a working first version with the initial 2 tabs and beginning to code the functionalities really fast. It also allowed running the application in both mobile platforms without any major problem.

- The navigation and functionality is smooth and worked well in both platforms. Additionally, the look and feel of both versions: iOS and Android is native. No changes on the UI were needed for this “native” adaptation.

- The window hierarchy and its management by Titanium SDK allow flexibility and scalability.

- Each module was decomposed into different controllers with their corresponding views. This design decision supported by the MVC framework allowed a better decoupling of the components. It also provided the possibility of reusing modules or having global functionality throughout the application.

3.5.3. Problems found with Titanium Appcelerator

Targeting several mobile platforms can produce difficulties at the moment of developing a cross-platform application; the process to adapt the same product to
different environments can become a challenge to the designers and developers. The following list contains the problems found during the development of the case study:

- The design and the requirements needed the usage of a plug-in or widget for being able to create a button menu. However, the plug-in was not completely adapted for some Android devices that required spending time to customize the widget library looking for a solution. At the end, the final decision was to discard the widget and create the same button menu “by hand” which at the end resulted better.

- It was decided to use the latest version of Titanium SDK and Titanium API because it has compatibility with iOS7 (the latest OS for Apple mobile devices) which created troubles at the beginning based on compatibility errors for deploying the application. This fact delayed the development of the prototype until the entire development environment was working correctly.

- During the debug phase of the implemented functionality, some bugs appeared while testing the app in iOS and Android devices as some functionality did not work correctly; some platform based workaround had to be done in order to provide the desired look and feel as well as the interaction with the users.

- In some cases, creating a special behavior or functionality on both platforms required that specific code be generated to use certain properties, functions or events that are only provided by one of the mobile platforms. Some platform-based workaround had to be done in order to provide the desired look and feel as well as the interaction with the users.

- Displaying the information on the webView caused troubles, as the content must fit to the device size. Titanium Appcelerator provides functionality to do it; but the scaled content was too small. A similar issue happened while opening PDF documents; to solve the PDF issue, an external PDF reader was implemented.

To solve this issue, it required a research to address the best solution for resizing the content. In this case, the solution creates a conflict with the base URL and the images and other resources within the original website displayed are lost.

The final solution was to show the content and hide the non-displayed images and links for the moment.

- The functionality of “Pull to Refresh” typically of iOS devices is not completely implemented in the Alloy mode. There are widgets and plug-ins which support these services but they are not official and, additionally, their maintenance is reduced because Appcelerator wants to include it on the Alloy framework. Moreover, this functionality does not work on Android.

### 3.6. Evaluation of the Cross-platform Prototype: First Usability test

This section contains the design, the results and the analysis of the first usability test. This usability test is part of the UCD approach and was used to refine the prototype and evaluate the performance of the requirements against real users in order to ensure
that the second version of the prototype (the one used for the comparison study with the native versions) had a minimum level of usability.

### 3.6.1. Design of the usability test

- **Introduction:**

  This is an application for students, professors and service staff have quick and convenient access from their mobile devices to updated and relevant information about news, events and announcements that occur on the campus of the School, as well as contact information of the different units, departments or services, and specific information about degrees and subjects taught at the center.

  This test is formed by five specific tasks on the application. The objective was to evaluate if the prototype was suitable for a user (students, professors and service staff). The idea was to detect problems and improve the usability and the design of the final product.

  During the test, the time required to perform each task was measured and also some notes were taken in order to understand and record the actions of the users while performing a certain task.

  After performing tasks, the users were asked to answer a satisfaction questionnaire to know and record the users’ impressions about the tasks and about application itself.

- **Users:**

  For this test, the participants were students from the school. All of them have not tested or used the former native versions of the application. The only restriction for being part of the test was that the students have experience using one of the platforms. They had tested the prototype on that platform.

- **Context of product use in the test**

  - **Test Facility:** The tests were conducted on the Software Engineering Laboratory. In this controlled environment, the actions and impressions of the users could be fully recorded and taken into account.

  - **Participants computing environment:** The full running prototype version was installed on devices from the Laboratory to be used as tested devices.

  - **Display devices:** The participants tested the prototype on an iPhone 4S (for the iOS version) and a Sony Xperia Z (for the Android version).

    The satisfaction questionnaires were presented on paper to be completed by the users after using the app. The questionnaires are on Annex A.
Test procedure

Scenario to be tested

- Scenario 1: Read a piece of news
  This task was created to see if the users could find specific piece of news and could open its detail to look for a specific piece of information.

- Scenario 2: Look for the office and phone number
  This task was created to test if the users were able to find the contact information of a certain person who works in a department or service of the School. The main idea was to know if the participants could find the service or department and then a specific person.

- Scenario 3: Look for contact information of a professor
  The objective of this task was to find a professor and look for his/her contact information.

- Scenario 4: Search for an activity
  This task was meant to test the events functionality. The participants had to find a specific event and then access to its information for finding specific data.

- Scenario 5: Look for information about a subject
  This task tried to test the process for accessing to the information of a subject. Also this task included having access to the study guide, which is another component of the subject information.

- Scenario 6: Exploration
  This task was meant to test the complete application based on unexpected actions performed by the users. The objective was to recover the ideas and thoughts of the users while they explored the application.

Participants general Instructions

The prototype of this application is created to allow an easy access to the information generated by the school to all the members of the university community; this means, students, professors and staff who works at the different services of the university. The main aim is to facilitate searching for information.

This test is formed by five specific tasks on the application. The objective is to evaluate if the prototype is suitable for a user like you. The main idea is to detect problems and improve the usability and the design of the final product.

During the test, the time required to perform each task was measured and also some notes were taken in order to understand and record the actions of the users while performing a certain task.
After performing tasks, the users were asked to answer a satisfaction questionnaire to know and record the users’ impressions about the tasks and about application itself.

- **Participants task instructions**

  - **Task 1: Read a piece of news**
  Today in the morning someone told you that in official school website is published information about a new Facebook page and Twitter account of the school; you want to read the complete information and find out which is the Twitter account.

  - **Task 2: Look for the office and phone number**
  Next year you want to go as Erasmus student to France for finishing your studies and also for improving your French because the job market in Spain is complicated.

  On your way home, you think in all the information that you need and you look for an empty spot on your agenda to go to the International Office and ask to Paloma Vivas for all the requirements and the documentation to request an Erasmus scholarship.

  How do you use the application to find out her office and her telephone number in the ETSIINF’s International Office?

  - **Task 3: Look for contact information of a professor**
  You and your classmates are doing a practical assignment of a subject of the “Departamento de Lenguajes y Sistemas” and you have doubts. You want to send an email to the professor Tomás San Feliu, and keep working on other assignments.

  How do you find out the email address and the office of your professor?

  - **Task 4: Search for an activity**
  Your cousin is on 2nd High School year and has asked you about the ETSIINF because he/she would like to study in this school. You remember about the “Jornada de Puertas Abiertas” which is activity to show about the school to potential new students. You decide to use the app to find out the date and the enrollment process for this activity.

  How would you look for the required information about “Jornada de Puertas Abiertas”?

  - **Task 5: Look for information about a subject**
  A new semester is starting and you are thinking to take the “Concurrencia” subject of the 2nd course in the degree of Informatics' Engineering; you would like to read the subject contents guide for being able to decide.

  How would you look for the subject contents guide and the professors of that subject?
- **Task 6: Exploration**
  Now it’s time to explore the application on your own. For instance, think about some information you would like to find and tell us how you plan to access to it or where do you think it should be located.

- **Performance and satisfaction metrics**

  The metrics evaluated in this test are the efficiency (time spent in carrying out each task), effectiveness (rate of task completion and number of errors) and the satisfaction of the users while performing the tasks and during the exploration of the application (measured with the questionnaire in Annex A).

### 3.6.2. Results of the usability test

- **Methodology**

  For this test, there was an information message sent on Twitter asking for volunteers to test the prototype of the application. Also, a poster with the announcement was hung on the Laboratory door. Other participants were recruited from the halls of the school.

  Each participant had an introduction about the test and the objective of the application. Then a survey was done for obtaining general information about the participants and their experience with the selected mobile platform and the official website of the school.

  After completing the first questionnaire, each participant had to read the tasks and tries to execute them (one by one). While the participant execute the task, the time was measured and some notes were taken to record the participant’s performance.

- **Participants**

  The participants selected for this usability test were students of different courses. One of the requirements in the selection process was having experience in the platform (either iOS or Android) and be currently using such platform. Another requirement was that the participant had not tested the native version of the application during the usability test of 2013; because the main aim was to get the impressions of first-time users.

  The test was done with 14 students: 10 male and 4 female. The 14 participants were divided according to the mobile platform that they use. Therefore, 7 participants tested the prototype on iOS and 7 on Android. The average age of the students is 21 years old.

  There were two testing days. On March 5th, the first 5 participants have performed the tests and the other 9 participants have done the test on March 6th. All the participants on the test were able to complete and finish all the tasks. The average time of the test was 17.5 minutes.
• **Evaluation of the Tasks**

The results of each task are shown according to the mobile platform used by the participant. The data is summarized on a table and plot in a bar graph; for each scenario is also included the corresponding question of the satisfaction questionnaire.

• **Task 1: Read a piece of news**

On average, the participants needed around 18 or 19 seconds to complete the task. Most of the participants did not commit an error while performing this task. Table 3.3 contains the times and errors for both platforms.

**Table 3.3: Task 1 Time and Errors by Platform**

<table>
<thead>
<tr>
<th></th>
<th>Android</th>
<th></th>
<th>iOS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (sec.)</td>
<td>Errors</td>
<td>Time (sec.)</td>
</tr>
<tr>
<td>P1</td>
<td>20</td>
<td>0</td>
<td>P1</td>
</tr>
<tr>
<td>P2</td>
<td>9</td>
<td>0</td>
<td>P2</td>
</tr>
<tr>
<td>P3</td>
<td>15</td>
<td>0</td>
<td>P3</td>
</tr>
<tr>
<td>P4</td>
<td>10</td>
<td>0</td>
<td>P4</td>
</tr>
<tr>
<td>P5</td>
<td>17</td>
<td>0</td>
<td>P5</td>
</tr>
<tr>
<td>P6</td>
<td>16</td>
<td>0</td>
<td>P6</td>
</tr>
<tr>
<td>P7</td>
<td>40</td>
<td>1</td>
<td>P7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>127</td>
<td>1</td>
<td>TOTAL</td>
</tr>
<tr>
<td>AVG</td>
<td>18</td>
<td></td>
<td>AVG</td>
</tr>
</tbody>
</table>

**Satisfaction Question:**
Do you think it was easy to find the news?

Table 3.4 and Figure 3.1 illustrate the results of the satisfaction question.

**Table 3.4: Task 1 Satisfaction Question**

<table>
<thead>
<tr>
<th>Totally Disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Totally Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

**Figure 3.1: Task 1 Satisfaction Question**
• **Task 2: Look for the office and phone number**

The participants required more time to find the information in iOS than in Android.

The majority of participants made mistakes on this task due to the lack of knowledge for finding the information of the International Office. Many participants found this task difficult to perform but all of them have achieved the goal of finding the contact information. Table 3.5 contains the times and errors for both platforms.

**Table 3.5: Task 2 Time and Errors by Platform**

<table>
<thead>
<tr>
<th></th>
<th>Android</th>
<th></th>
<th>iOS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (sec.)</td>
<td>Errors</td>
<td>Time (sec.)</td>
<td>Errors</td>
</tr>
<tr>
<td>P1</td>
<td>40</td>
<td>1</td>
<td>P1</td>
<td>172</td>
</tr>
<tr>
<td>P2</td>
<td>27</td>
<td>1</td>
<td>P2</td>
<td>126</td>
</tr>
<tr>
<td>P3</td>
<td>50</td>
<td>2</td>
<td>P3</td>
<td>53</td>
</tr>
<tr>
<td>P4</td>
<td>54</td>
<td>0</td>
<td>P4</td>
<td>89</td>
</tr>
<tr>
<td>P5</td>
<td>50</td>
<td>1</td>
<td>P5</td>
<td>30</td>
</tr>
<tr>
<td>P6</td>
<td>14</td>
<td>0</td>
<td>P6</td>
<td>22</td>
</tr>
<tr>
<td>P7</td>
<td>16</td>
<td>0</td>
<td>P7</td>
<td>31</td>
</tr>
<tr>
<td>TOTAL</td>
<td>251</td>
<td>5</td>
<td>TOTAL</td>
<td>523</td>
</tr>
<tr>
<td>AVG</td>
<td>36</td>
<td></td>
<td>AVG</td>
<td>75</td>
</tr>
</tbody>
</table>

**Satisfaction Question:**
Do you find quick and easy the contact information of a person who works in the International Office?

Table 3.6 and Figure 3.2 illustrate the results of the satisfaction question.

**Table 3.6: Task 2 Satisfaction Question**

<table>
<thead>
<tr>
<th>Totally Disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Totally Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>3</td>
<td>0</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>
Task 3: Look for contact information of a professor

This task was easier for the participant and the majority of them did not make mistakes. The times for performing the task in both platforms are similar; therefore, it can be inferred that the interaction is not affected by the platform. Table 3.7 contains the times and errors for both platforms.

Table 3.7: Task 3 Time and Errors by Platform

<table>
<thead>
<tr>
<th></th>
<th>Android</th>
<th></th>
<th>iOS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (sec.)</td>
<td>Errors</td>
<td>Time (sec.)</td>
<td>Errors</td>
</tr>
<tr>
<td>P1</td>
<td>98</td>
<td>1</td>
<td>P1</td>
<td>45</td>
</tr>
<tr>
<td>P2</td>
<td>48</td>
<td>1</td>
<td>P2</td>
<td>20</td>
</tr>
<tr>
<td>P3</td>
<td>49</td>
<td>0</td>
<td>P3</td>
<td>31</td>
</tr>
<tr>
<td>P4</td>
<td>37</td>
<td>0</td>
<td>P4</td>
<td>17</td>
</tr>
<tr>
<td>P5</td>
<td>21</td>
<td>0</td>
<td>P5</td>
<td>44</td>
</tr>
<tr>
<td>P6</td>
<td>23</td>
<td>0</td>
<td>P6</td>
<td>51</td>
</tr>
<tr>
<td>P7</td>
<td>28</td>
<td>0</td>
<td>P7</td>
<td>50</td>
</tr>
<tr>
<td>TOTAL</td>
<td>304</td>
<td>2</td>
<td>TOTAL</td>
<td>258</td>
</tr>
<tr>
<td>AVG</td>
<td>43</td>
<td></td>
<td>AVG</td>
<td>37</td>
</tr>
</tbody>
</table>

Satisfaction Question:
Do you find quick and easy the contact information of a professor?

Table 3.8 and Figure 3.3 illustrate the results of the satisfaction question.

Table 3.8: Task 3 Satisfaction Question

<table>
<thead>
<tr>
<th></th>
<th>Totally Disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Totally Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>
Task 4: Search for an activity

In this task, any of the participants made mistakes and their behavior reflected that it was completely clear how to find the required event and its information. Table 3.9 contains the times and errors for both platforms.

Table 3.9: Task 4 Time and Errors by Platform

<table>
<thead>
<tr>
<th></th>
<th>Android</th>
<th></th>
<th>iOS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (sec.)</td>
<td>Errors</td>
<td>Time (sec.)</td>
<td>Errors</td>
</tr>
<tr>
<td>P1</td>
<td>25</td>
<td>0</td>
<td>P1</td>
<td>33</td>
</tr>
<tr>
<td>P2</td>
<td>14</td>
<td>0</td>
<td>P2</td>
<td>14</td>
</tr>
<tr>
<td>P3</td>
<td>8</td>
<td>0</td>
<td>P3</td>
<td>20</td>
</tr>
<tr>
<td>P4</td>
<td>7</td>
<td>0</td>
<td>P4</td>
<td>20</td>
</tr>
<tr>
<td>P5</td>
<td>17</td>
<td>0</td>
<td>P5</td>
<td>14</td>
</tr>
<tr>
<td>P6</td>
<td>21</td>
<td>0</td>
<td>P6</td>
<td>23</td>
</tr>
<tr>
<td>P7</td>
<td>15</td>
<td>0</td>
<td>P7</td>
<td>17</td>
</tr>
<tr>
<td>TOTAL</td>
<td>107</td>
<td>0</td>
<td>TOTAL</td>
<td>141</td>
</tr>
<tr>
<td>AVG</td>
<td>15</td>
<td></td>
<td>AVG</td>
<td>20</td>
</tr>
</tbody>
</table>

Satisfaction Question:
Do you find the information about the “Jornada de Puertas Abiertas” without any difficulties?

Table 3.10 and Figure 3.4 illustrate the results of the satisfaction question.

Table 3.10: Task 4 Satisfaction Question

<table>
<thead>
<tr>
<th></th>
<th>Totally Disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Totally Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>9</td>
</tr>
</tbody>
</table>
Task 5: Look for information about a subject

According to the retrieved information, the participants did not make mistakes while performing this task. Therefore, it can be inferred that it is totally clear how to find this information.

The times in both platforms are similar for all the participants. Table 3.11 contains the times and errors for both platforms.

Table 3.11: Task 5 Time and Errors by Platform

<table>
<thead>
<tr>
<th>Platform</th>
<th>Time (sec.)</th>
<th>Errors</th>
<th>Time (sec.)</th>
<th>Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Android</td>
<td></td>
<td></td>
<td>iOS</td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>18</td>
<td>0</td>
<td>P1</td>
<td>23</td>
</tr>
<tr>
<td>P2</td>
<td>12</td>
<td>0</td>
<td>P2</td>
<td>25</td>
</tr>
<tr>
<td>P3</td>
<td>18</td>
<td>0</td>
<td>P3</td>
<td>28</td>
</tr>
<tr>
<td>P4</td>
<td>15</td>
<td>0</td>
<td>P4</td>
<td>26</td>
</tr>
<tr>
<td>P5</td>
<td>25</td>
<td>0</td>
<td>P5</td>
<td>34</td>
</tr>
<tr>
<td>P6</td>
<td>24</td>
<td>0</td>
<td>P6</td>
<td>25</td>
</tr>
<tr>
<td>P7</td>
<td>27</td>
<td>0</td>
<td>P7</td>
<td>20</td>
</tr>
<tr>
<td>TOTAL</td>
<td>139</td>
<td>0</td>
<td>TOTAL</td>
<td>181</td>
</tr>
<tr>
<td>AVG</td>
<td>20</td>
<td></td>
<td>AVG</td>
<td>26</td>
</tr>
</tbody>
</table>

Satisfaction Question:
Do you find the information about the subjects without any difficulties?

Table 3.12 and Figure 3.5 illustrate the results of the satisfaction question.

Table 3.12: Task 5 Satisfaction Question

<table>
<thead>
<tr>
<th></th>
<th>Totally Disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Totally Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>10</td>
</tr>
</tbody>
</table>
Task 6: Exploration

In this case, there was no time or errors measured because the objective is to see the users’ behavior and also their reactions while interacting with the application.

Summary of times and errors by task and platform

The table 3.13 contains the average values for the time and the total number of errors of the participants.

Table 3.13: Summary of times and errors by task and platform

<table>
<thead>
<tr>
<th>Task</th>
<th>Android Time (sec.)</th>
<th>Android Errors</th>
<th>iOS Time (sec.)</th>
<th>iOS Errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>18</td>
<td>1</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Task 2</td>
<td>36</td>
<td>5</td>
<td>75</td>
<td>11</td>
</tr>
<tr>
<td>Task 3</td>
<td>43</td>
<td>2</td>
<td>37</td>
<td>2</td>
</tr>
<tr>
<td>Task 4</td>
<td>15</td>
<td>0</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Task 5</td>
<td>20</td>
<td>0</td>
<td>26</td>
<td>0</td>
</tr>
</tbody>
</table>

General Evaluation of the Application

As part of the satisfaction questionnaire, the participants had to complete a couple of questions to evaluate the possible problems on the prototype as well as the positive aspects of it. In the following paragraphs are stated the comments of the users about their experience with the application:

- “The application is an easy way to search for useful information. The navigation and interaction is simple and easy. Having access to the professors contact information in a simple way is important”.
- “The app is intuitive and easy to use. It is very clear”.

Figure 3.5: Task 5 Satisfaction Question
- “I think the app is good, facilitates searching for information. It contains the most important information used by students in their daily activities. Important to have easy access to subjects’ information”.

- “The application is intuitive, clear, simple and useful to find information without entering to the official website of the school. Personally I would redistribute the spaces of the submenu buttons”.

- “I would use this app frequently as it contains all the information I usually need. It is easy to understand as the start screen allows access to everything at first glance”.

- “It is a good app, allows a fast access to information. Information is more manageable in the app than in the website. However, not all the options of the website are available on the app”.

- “The application contains important information. I would use mostly the Subject part and maybe events but always something related to my studies. The application allows easy access to find professors contact information and the subjects' guides.”

- “The app is clear, the information is displayed clearly and without any extra animations or unnecessary effects; I found that very important”.

- “It is very clear and the application follows the characteristics of the mobile platform (Android case). Fast and easy access to the information”.

- “I had a successful experience; the app is easy and simple. It provides all the usually information needed by a student”.

- “Satisfactory experience in general. The submenus (icons) are confusing because I don’t know the difference between News and Adverts for example”.

From the retrieved information, we can infer that the concept of the app was successfully received by the users. Additionally, the interaction and the navigation were successful generating a good UX. Moreover, the evaluation in terms of usability was satisfactory by most of the participants.

- **New functionalities suggested for the Application**

  On the satisfaction questionnaire, the participants had to propose extra functionalities or something that is missing on the actual prototype. The following list is composed by the six most popular suggestions (number of participants suggesting each one is detailed in brackets):

  - Add a search bar for the contacts lists and for subjects (5 participants).
  - Filter subjects by course (5 participants).
  - Connect the application to Moodle either providing the URL link or integrating Moodle in the app (4 participants).
3.6.3. Analysis of the usability test

Based on the results obtained from the test, it is clear that the participants have problems to understand the differences of the elements form the bulletin board module. This fact generates confusions to 50% of the participants as the differences between News and Adverts are not clear. The lack of knowledge caused errors while performing the task, concretely on 28% of the test participants.

The difference between Departments and Services causes also problems to 28% of the participants. This problem is the reason why the 57% of the users made mistakes on the task 2 (finding contact information of the International Office) but on the task 3 (finding contact information of a professor) only 29% of the participants had mistakes. The required information to complete both tasks was on the same submenu (ETSIINF Staff). Therefore, the time required to learn these functionalities is reduced and after the first-time most of the users understood the difference between Departments and Services and the information provided by both options.

Despite the facts mentioned above and confusion created by the names, 64% of the participants considered that the information presented was clear.

Moreover, 57% of the participants considered that the icons of the submenus caused some confusion. Especially the icon of Adverts was not clear, but the misunderstanding comes from the concept; the users did not understand completely which information they can find there.

On the other hand, 93% of the participants mentioned that the application is easy to use and allows to user a simple way to access to relevant information for them. They also found the distribution of the contents clear and helpful at the moment of looking for information.

Furthermore, 93% of the users mentioned that they would use the application if it were available on the platforms application markets. However, only 78% said that the application provides the information they would look for; in most of the cases some extra functionalities were required.

Finally, 71% of the participants look for information related to their studies and mentioned that the information provided by the application is important for them.

The obtained information shows that the prototype in its current version is identified as useful by test participants, ensuring a minimum level of usability. The next version, where the main usability problems are fixed, can serve the purpose of the current research work as a real case study, since the application is useful as it is for the intended users (students).
• **Main usability problems**

  • The lack of knowledge about the information contained by the options of the bulletin board can cause confusion between the users. The icon of Adverts causes confusion or misunderstanding.

  • After seeing that the users had to scroll a lot and many times they get lost on the lists looking for a specific subject or a specific professor. The lists should have some functionality to filter the results of the table.

  • A student could need to access a professor’s contact data without knowing the department he/she belongs to. Having the possibility to access to the professor's data directly, just searching by name, would be handy in such situation.

  • Specifically on Android, a couple of users missed a back button on the application title bar. However, according to design guidelines of the platform this component is not an Android basic component.

  • On Android, a couple of users did not identify the events and adverts as clickable elements; in order to access more detailed information.

The table 3.14 contains the severity index and the estimated time of each usability problem detected. The severity index goes from 1 (non-critical) to 5 (extremely critical).

**Table 3.14: Severity index of the usability problems found**

<table>
<thead>
<tr>
<th>Problem</th>
<th>Severity Index</th>
<th>Estimated Time</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confusion with the bulletin board options</td>
<td>2</td>
<td>1 – 2 days</td>
<td>As the names used are the same of the official website, there is not so much freedom to change the classification. However, just the display names can be changed to help the users.</td>
</tr>
<tr>
<td>Search Filters for subjects</td>
<td>3</td>
<td>2 – 3 days</td>
<td>Search bar and filter by course will be implemented</td>
</tr>
<tr>
<td>Search Filters for staff information</td>
<td>3</td>
<td>1 day</td>
<td>Search bar will be implemented</td>
</tr>
<tr>
<td>Android back button</td>
<td>1</td>
<td>1 day</td>
<td>The adaptation of Titanium to the design guidelines does not offer it by default. It has to be specifically coded.</td>
</tr>
<tr>
<td>Events and Adverts identified as clickable elements</td>
<td>1</td>
<td>N/A</td>
<td>Only 2 participants realized about it. Not very relevant</td>
</tr>
</tbody>
</table>
On the second version the prototype (the one actually used for the comparison study), some design decisions were taken in order to solve these problems. The issue about the back button on Android was not considered as Titanium does not offer this behavior by default; implementing this functionality would require changes on the Titanium SDK core.

### 3.6.4. Conclusions of the usability test

Based on the results obtained from the prototype usability test and the information obtained about the participants’ behavior and their interaction with the application the following conclusions were obtained:

- Some concepts are not clear and not comprehended by the students. The division and the name used on the prototype are the same as the official website or the ones used officially in the University but most of them are not known by the students.

  However, once the participants have entered on each menu they were able to comprehend and understand the division of information. Some of the participants even mentioned the division has sense and is correct but at first sight they were not able to interpret this separation correctly.

- The information provided by the bulletin board is confusing for many participants as the category names are similar and the difference is not clearly stated in their knowledge.

- As some concepts are not clear, the icons used on the submenus can cause confusion and lead the users to make mistakes at the moment of looking for some concrete information.

- The navigation and the interaction of the application is fluid, simple and easy to understand by a first-time user. The participants’ impressions were very good about this topic; they liked the interaction and the organization of the information.

- The users found the application useful as it allows easy and fast access to specific information about the school and about their studies. Most of them said they would download the application and use it frequently to look for information.

- Some options of the application join information that usually requires a lot of time to find in the official website and based on this fact, the application can be very popular on the university community.

- Extra functionalities can be added to future versions of the application to allow access to other services of the University.

- Most of the students had a satisfactory experience as first-time users of the application; they liked the concept and the easiness to find specific information without requiring a browser to enter to the official website of the school.

- It takes a small amount of time to learn how to use the application and where is located everything. The participants were confident of keep using the application without any trouble after their first time interacting with it.
According to the information retrieved, the prototype's scope is correct because many of the users mentioned that the application already has useful information for their daily activities.

3.6.5. Future work

Refine the prototype taking into account the information obtained from the usability test as well as the suggestions proposed by the users. The extra functionalities have to be evaluated and its feasibility has to be analyzed to decide which ones can be implemented in the next version of the prototype. This new version of the prototype will be the one used to compare the cross-platform and the native development approaches on this work.
4. Study Design

The study was designed to evaluate the impressions of the participants after they tested both prototypes (the native and the cross-platform ones) and be able to compare and determine if the development approach used affects the UX of the application.

To accomplish the objectives of this work, two different usability tests were performed: laboratory test and longitudinal study. Each one has its own characteristics and details. The specification of the test protocol for each study is described by a customization of the Annex C of the Common Industry Specification for Usability – Requirements (CISU-R) document [CISU-R, 2007] according to our own objectives.

- **Laboratory test**: To evaluate the first impression of the users when they have not interacted with the prototype before. In this usability test, participants were asked to perform five specific tasks that covered some functionalities in the app. After each laboratory test, participants were asked to evaluate the prototype through a satisfaction questionnaire.

- **Longitudinal study**: Participants had five days to use the application freely under real circumstances. After finishing each 5-day usage period, users were asked to evaluate their satisfaction with the version of the app they had been using. Longitudinal studies are especially important in the testing of mobile applications, since the different contexts where mobile devices are typically used are difficult to reproduce in a controlled environment.

Figure 4.1 shows a diagram of all the phases that a participant must complete during the entire study. First, the admission process to the study where the participants must fulfill two principal requirements: having at least 6 months of experience using one mobile platform (iOS or Android) and not being part of the usability test of previous versions of the apps. Next, the participants had to complete the test of one version of the application either native or cross-platform, and then they had to evaluate that version. The following step was the 5-day usage period, when participants could test freely the app on their daily activities; when the 5-day usage period was completed, they had to evaluate the prototype again.

Figure 4.1: Diagram of the study phases for each participant.

This process must be repeated with the other prototype. When both prototypes have been tested, a final evaluation is completed on which the participants compared their experience with both versions.
The participants were selected among the students of the School of Computer Science at UPM using a registration website. Each participant has to complete the laboratory test, evaluate the prototype and complete the longitudinal study. Once these three phases are completed with one prototype, the process has to be repeated with the other one. At the end of the testing period, the participants were asked to complete the last evaluation to compare their experience with both applications. To avoid adaptation times, the participants used their own smartphones where the application was installed.

We have selected a group of usability attributes as the variables to be assessed in this work. The selected variables are: effectiveness, efficiency and satisfaction. The different methods mentioned in the section 4.1 provide the necessary information to measure the different values.

In the following paragraph each variable is described:

- **Effectiveness**: It represents the completeness and accuracy with which users achieve and perform certain tasks. This variable is measured in our study as the number of successfully completed tasks from the task list of the usability test. Additionally, the number of errors while performing the task is recorded; mistakes can be categorized according to its severity and how easily the users can recover from them.

- **Efficiency**: It is defined as the time required by the users to accomplish a task while interacting with the application. Each task should have a determined time on which the users have to finish it. Having the time baseline, each user’s time can be compared and the differences can be established.

- **Satisfaction**: This measure shows the attitude and the reaction of the user toward using the application. This variable is measured by gathering the impressions of the users after the test, using specific questionnaires for this purpose.

### 4.1. Usability Evaluation Methods

For the laboratory test, the methods chosen are: satisfaction questionnaires, performance measurement and interviews. For the longitudinal study, the methods selected are: remote data collection and satisfaction questionnaires.

Next, the usability evaluation methods chosen for the study are detailed.

#### 4.1.1. Questionnaires

This technique gathers the users’ subjective impressions of the system [Nielsen, 1993]. The main aim is to obtain general opinions of the system as well as information about specific characteristics related to the analysis of a concrete behavior or subject.

The application of a questionnaire provides benefits for the researchers as it is an inexpensive method and easy to administer to the participants. It also increases the privacy of the participant’s answers [Delikostidis, 2007].

The questions must be clear and direct in order to be able to obtain the desired information, as there is no physical interaction between the researcher and the participant.
For the purposes of this study, it was decided to apply three different questionnaires to gather the participants’ impressions about each version of the application and to identify possible differences between the creation of an application using native and cross-platform approaches in terms of user experience.

The first one is the System Usability Scale (SUS); a customized and reduced version of the User Experience Questionnaire (UEQ) to focus on the only aspects that were applicable to the app context of use; and an ad-hoc questionnaires where participants were asked to compare the version of the app tested with the look and behavior of a typical app in their platform.

- **System Usability Scale (SUS) [Brook, 1996] [usability.gov, 2014]**
  
The System Usability Scale (SUS) provides a reliable tool for measuring usability. It is composed by a ten-item scale, giving a global view of subjective assessments of usability. Each question has five possible answers going from “strongly disagree” to “strongly agree”.

  John Brooke created the scale in 1986 and it allows the evaluation of a wide variety of services as hardware, software, mobile devices, applications and websites.

  SUS is not a diagnostic test. It has to be used to classify the ease of use of the application or the environment tested.

  The questionnaire provided to the participants is on Annex B. This questionnaire was applied in Spanish.

- **User Experience Questionnaire (UEQ) [UEQ, 2014]**
  
  This questionnaire allows a quick assessment of the user experience of interactive products. It is designed to allow the participants to express their feelings and impressions about a product after interacting and using it. The UEQ is a semantic differential.

  The questionnaire aims to consider and evaluate the hedonic aspects (non-task oriented quality aspects like impression, aesthetic, stimulation, etc.) and the pragmatic ones (task oriented quality aspects like: efficiency, learnability, etc.). Therefore, the scales of the questionnaire are designed to cover a comprehensive impression of user experience [Rauschenberger et al., 2012].

  The original scales are: attractiveness, perspicuity, efficiency, dependability, stimulation and novelty [Rauschenberger et al., 2012]. For being able to focus on the app context of use, a reduced version of UEQ was used. It considers five of the original scales: attractiveness, perspicuity, efficiency, dependability (not all questions considered) and novelty.

  The questionnaire provided to the participants is on Annex C. This questionnaire was applied in Spanish.

- **Ad-hoc Questionnaires**
We have defined additional questionnaires to evaluate other aspects, which concern to the main objective of this work, and that are not covered by SUS or by UEQ.

One questionnaire is dedicated to compare the users’ impressions about their interactions with the native and the cross-platform versions of the application. The questionnaire is meant to evaluate if the participants consider that both versions of the app behave as any other application of the targeted platforms. This questionnaire is on Annex D. It was applied in Spanish.

For the longitudinal study, we used the same questions of the laboratory test with some extra questions about the functionalities used by the participants added. The objective was to be able to compare the participants’ perception after about the apps after the 5-day usage period. The questionnaire was in Spanish and is on Annex E.

The other questionnaire is meant to gather and register the impressions and the final evaluation of the participants to both versions. This questionnaire was applied after the tests and the free testing period. Its objective is to determine the preferences of each participant. The questionnaire provided to the participants is on Annex F. It was applied in Spanish.

The information obtained from both questionnaires will help to determine differences between the native and cross-platform versions as experienced by users.

4.1.2. Usability Tests

It is the fundamental method for testing the usability of a prototype or a product. This technique provides direct information on how people interacts with a determined product and shows up the problems while testing a concrete interface or functionality. It can be seen as an irreplaceable practice because it provides real input about the performance of real users [Nielsen, 1993].

The usability tests help to ensure that the users of a system can carry out the intended tasks efficiently, effectively and satisfactorily [Gaffney, 1999]. These tests offer decision criteria about the system usability. The criteria obtained are more objective than the one obtained just form functionality tests done by the developers because the impressions are obtained from real users [Ferré, 2005]. Usability tests have usually four stages: preparation, introduction, testing and elaborating the test report [Nielsen, 1993].

For these tests, the participants are asked to perform the most representative tasks of the system, possibly while some performance measurement is carried out. Reactions of the user while performing the tasks are observed and recorded for a subsequent analysis.

Having the quantitative values from performance measurement, the actual usability of the system on terms of efficiency will be reflected [Ferré, 2005]. This approach should be used when the efficiency is a relevant aspect of the test as this work is actually focused on.

The tests can also measure the effectiveness of each user while performing the set of tests. These values can provide an overview about how easy to understand is the system or if a specific task generates problems under determined circumstances.
To establish the environment of the usability tests, the document *Specification of a usability test protocol* was used. This document is a template described in the Annex C of Common Industry Specification for Usability – Requirements (CISU-R) from the National Institute of Standards and Technology of the U.S. Department of Commerce [CISU-R, 2007].

For our study, the template presented in the CISU-R has been customized for the purposes and the nature of the experiment.

**4.1.3. Remote data collection / Analytics**

The usage of analytics and recording data about the software products has been traditionally associated to marketing, sales or business reports, and it has been less common its use related to user experience evaluation. This stereotype is currently changing, as many UX professionals realize about the importance of having real data on which they can rely as a source to help them in their research and design decisions.

The information recorded about the behavior of the users is called *analytics*. This information can help the UX professionals and developers to improve the user experience of their final products by learning about their users and their behavior.

The analytics service is provided by many companies as a service (SaaS) to record and store the data originated by the usage of an app. Analytics can be used for recording and storing information obtained from the usability studies, allowing the researchers to perform a posterior analysis and interpretation of results, to use them as a support tool for taking decisions to improve the application.

From the UX point of view, mobile analytics are a really good tool that can help to measure and determine the reactions of a user while interacting with an application. The information obtained can give early warning signals of a problem in some feature of the application.

The usage of analytics can be applied to record data from studies in controlled environments, as well as to record data from real life studies. Analytics need to be included into mobile applications to have a constant monitoring of the application and the interaction of the users inside the application.

This technique will be applied for the laboratory usability tests and for the longitudinal usability study, obtaining analytics of the usage of the different versions of the apps (iOS and Android versions generated with native and cross-platform approach). The solution used for the experiment for recording the data is Google Analytics.

- **Google Analytics** [Google Analytics, 2013]

  This service is very complete and strong as Google provides it. The service can be accessed from everywhere since it is web-based. Its usage is simple to understand and the reports can be customized. It allows the developers to have a lot of information about their applications such as: number of downloads, devices used, crashes, active users, recurrent users, among others.

  It offers special SDKs for working and integrating the Analytics platform directly with iOS or Android applications. It also provides tutorials and dedicated information to the developers, and a complete interface to analyze the data.
generated with charts and graphics. This service includes a web part, which can be used to insert the corresponding code on the cross-platform application if it doesn’t allow the compatibility with the native Analytics SDK libraries.

As this tool is well known and popular in the market and in the development mobile apps world, there are some third party modules or plugins to integrate the Analytics service from Google with the application that is developed in the cross-platform frameworks.

For a usability experiment, the data provided may be not enough and a complementary survey or data collection would be required. On the other hand, it provides useful information and also real time features which can be used during the experiment to follow the behavior of the users.

The service is focused on analyzing mobile applications and therefore the information provided includes the devices, the operating systems and even a navigation flowchart of the visited screens during the interaction with the application.

4.2. Laboratory Test

- Introduction

The laboratory test was the first study performed for analyzing the usability of the ETSI-INF-app in its native and cross-platform versions. The main objective of these tests was to evaluate the participant’s first impression with the applications. Both apps are designed and developed for running in the most popular mobile platforms: iOS and Android.

This test was performed in a controlled environment with a limited number of users that are separated according to the mobile platform that they usually use.

The users had to complete a certain list of tasks and interactions with the application. The performance of the users was measured to obtain necessary information for being able to assess the different usability values. Other techniques used as part of this study were: satisfaction questionnaires and remote data collection using Google Analytics.

The participants had to interact with the native and the cross-platform version of the application trying to perform the same tasks using both of them. The intended result is to determine the differences in the usage of both versions of the application.

- Users

The participants for the study were selected among the students. For the selection process, we decided to follow a random process on which the filters to choose the final participants were at having least 6 months of experience using iOS or Android and had not participated in previous usability tests of the application.

The participants’ selection represents a proportional sample of the real future users of the application and it follows the worldwide tendency of mobile platform usage in terms of platform market share [IDC, 2013].

- Context of product use in the test
Test Facility

The laboratory test was performed in the Software Engineering Laboratory of the School of Computer Science at UPM. The testing environment was controlled to avoid distractions and being able to observe the users reactions and measure their performance on each task.

The testing facility was chosen to facilitate data gathering in each evaluation session.

Participants computing environment

The participants use their own mobile devices to perform the test without any adaptation to a new mobile device as they use their own. The users will be provided with the corresponding links to download the testing applications.

Display devices

The testing applications were fully working prototypes displayed in the mentioned mobile platforms.

Moreover, the satisfaction questionnaires, which were part of the test, were presented online to be completed by the users in a computer at the laboratory.

Test procedure

Scenarios to be tested

- **Scenario 1: Read a piece of news**
  This task was created to see if the users could find specific news and could open its detail to look for a specific piece of information.

- **Scenario 2: Look for the next bus**
  This task was created to verify if the users were able to find the exact time of the next bus leaving the UPM Campus in direction to the city.

- **Scenario 3: Look for contact information of a professor**
  The objective of this task was to find a professor and look for their contact information.

- **Scenario 4: Search for an activity**
  This task is meant to test the events functionality. The participants have to find a specific event and then access to its information for finding specific data.

- **Scenario 5: Look for information about a subject**
  This task tried to test the process for accessing to the information of a subject. Also this task included having access to the study guide, which is another component of the subject information.

Participants general Instructions
Thanks for being part of this usability study about user experience in mobile applications. For this study we will ask you to try two different versions of a prototype of the future of our School App (ETSIINF-app).

This application is created to allow an easy access to the information generated by the school to all the members of the university community; this means, students, professors and staff who works at the different services of the university. The main aim is to facilitate searching for information having quick and convenient access from their mobile devices to date and relevant information on news, events and announcements that occur on campus, as well as contact information teachers and university staff members, also having access to the subjects’ information and study guides.

The objective is to evaluate if the application is suitable for a user like you. The main idea is to evaluate the application not to evaluate you. After performing the specific tasks, we will ask you to complete a satisfaction survey to know your impressions and feelings about the application.

During the test, the time required to perform each task will be measured and also some notes will be written in order to understand and record the actions of the users while performing a certain task.

As a participant, we will ask you to do the following activities:

- Perform a usability test of 20 minutes with one version. After 5 days, you have to come back to perform a usability test for the other version.
- Use the two versions of the application installed in your mobile phone and use them during 5 days as you consider.
- Complete a satisfaction survey of each version that you have used.

On the laboratory tests you will be asked to perform five specific tasks. Then you will have the application installed on your smartphone to test it freely during five days. Once the five days period is completed with both prototypes, you have to come back to the laboratory for a final evaluation survey to compare both versions.

- **Participants task instructions**

  - **Task 1: Read a piece of news**
    Today in the morning someone told you that a workshop of mobile applications development has taken place in the School for high school students; you want to read the complete piece of news and find out details about it.

    How would you use the application to find this information?

  - **Task 2: Look for the next bus**
    You are studying in the University and you want to know the exact time of departure of the next bus in direction to the city (Aluche).

    How would you look for the next bus departure time using the application?

  - **Task 3: Look for contact information of a professor**
You and your classmates are doing a practical assignment of a subject of the “Departamento de Lenguajes y Sistemas” and you have doubts. You want to send an email to the professor Tomás San Feliu, and keep working on other assignments.

How do you find out the email address and the office of your professor?

- **Task 4: Search for an activity**
  Your cousin is on 2nd High School year and has asked you about the ETSIINF because he/she would like to study in this school. You remember about the “Jornada de Puertas Abiertas” which is activity to show about the school to potential new students. You decide to use the app to find out the date and the enrollment process for this activity.

  How would you look for the required information about “Jornada de Puertas Abiertas”?

- **Task 5: Look for information about a subject**
  A new semester is starting and you are thinking to take the “Estructura de Computadores” subject of the 2nd course in the degree of Informatics’ Engineering; you would like to read the subject contents guide for being able to decide.

  How would you look for the subject contents guide and the professors of that subject?

### Performance and satisfaction metrics

- **Criteria and measurements**
  As mentioned earlier, the usability variables measured are: efficiency, effectiveness, satisfaction and errors.

  The main objective of the test is determining the differences existing between the native and cross-platform versions.

- **Metrics for effectiveness, efficiency and satisfaction**
  - **Effectiveness**: This variable can be measured as the number of successfully completed tasks from the task list of the usability test and the error rates.
  - **Efficiency**: This variable is measured as the time required by the users to accomplish a task while interacting with the application.
  - **Satisfaction**: It is measured recovering the impressions of the users after the test and also using specific questionnaires that retrieve this subjective information from the users. The questionnaires used are: SUS, UEQ and an ad-hoc questionnaire. See Annex B, Annex C and Annex D respectively.

### 4.3. Longitudinal Study
• **Introduction**

The longitudinal study was the second evaluation performed for analyzing the usability of the ETSIIINF-app in its native and cross-platform versions. This study had a different approach compared to the laboratory test. Depending on the preferences of the users, they had tested the application whenever they need it during their daily activities.

In this case, the environment was uncontrolled, there were no pre-established tasks; the users had to interact with the application in their own environment during a certain amount of time.

The performance of the users was measured using the remote data collection technique with Google Analytics.

After the testing period, the users had to complete the satisfaction questionnaires to obtain their impressions about the application.

• **Users**

The participants of this study were the same as the ones selected for the laboratory test.

The participants had to test and interact with the application in their natural environment. The objective was to analyze their behavior and how they interacted with the application under real circumstances.

• **Context of product use in the test**

  ❖ **Test Facility**

  In this case, it was not required a specific location because the participants were at their own environment and the tests on the application were during their daily life activities.

  The participants used their own mobile devices under natural conditions.

  ❖ **Participants computing environment**

  After being part of the Laboratory test, the participants had installed on their smartphones the different versions of the application either native or cross-platform and had to use them freely for a 5-day usage period.

  ❖ **Display devices**

  The testing applications were fully working prototypes displayed in the mentioned mobile platforms.

  Moreover, the satisfaction questionnaires, which were part of the test, were presented online to be completed by the users in a computer at the laboratory after five days of using the app.

• **Test procedure**

  ❖ **Scenario to be tested**
There are no specific scenarios as the participants had tested the app during their daily activities.

- **Participants general Instructions**

  After performing the Laboratory test, you have the prototype on your mobile device, you have to use the application when you consider necessary and test the different features according to your needs.

  You have to test the application freely for a five days period after which you have to return to the laboratory to get the other version and test it for another five days.

  Once both free testing periods are finished, the participants have to complete a questionnaire to evaluate and compare both versions.

- **Participants task instructions**

  You have to test the application freely using its features according to your needs. You have to use the application as part of your daily activities when you consider it necessary.

- **Performance and satisfaction metrics**

  - **Criteria and measurements**

    As mentioned above, the usability variables measured are: effectiveness, satisfaction.

    The main objective of the test is determining the differences existing between the native and cross-platform versions.

  - **Metrics for effectiveness, efficiency and satisfaction**

    - **Effectiveness**: This variable can be measured as the number of successfully completed tasks from the task list of the usability test.

    - **Satisfaction**: It is measured recovering the impressions of the users after the test and also using specific questionnaires that retrieve this subjective information from the users. The questionnaires used are: SUS, UEQ and an ad-hoc questionnaire. See Annex B, Annex C and Annex E respectively.
5. Results

In this chapter are presented all the results obtained in the usability study about the comparison of the native and the cross-platform versions of the ETSIINF application.

The study was conducted in the first two weeks of April 2014. A call for participants was made between students of the School of Computer Science at UPM. From the 68 respondents, 38 were selected because they were experienced users of either iOS or Android devices (they had more than 6 months experience), and they had not participated in the usability tests of the first prototype (so they had not previous knowledge of the logic of the applications).

From the original 38 participants selected to be part of the study, one of them did not finish with all the required participation, so the study was completed with 37 participants: 14 expert iOS users and 23 expert Android users.

From the 37 participants, 86.5% were male and 13.5% were female, with an age average of 23 years old. The majority of the participants were Undergraduate students (81%) and the rest were Master students (19%). The Android expert participants represented the 62% and the remaining 38% were iOS expert participants. These values represent the reality of mobile usage of the UPM [Barea et al., 2013] and also according to the worldwide tendency of mobile platform usage [IDC, 2013].

As mentioned on the study design, the participants have performed two test sets for the laboratory and the longitudinal study. The participants have been assigned randomly to one application (native or cross-platform) for the Test 1 and then the other version for Test 2. For a better understanding of the tests performed by the participants (see Figure 4.1).

The following sections contain the results obtained in all the phases of this study with all the information obtained the participants have tested both versions of the application. The results are presented as follows, first the results of the Laboratory test (both Test 1 and Test 2). Next, the results of the Longitudinal study (containing Test 1 and Test 2). Finally, the information of the final comparison between both versions of the application (Titanium or native)

5.1. Laboratory Test (First Impression)

The laboratory test measured the performance of the users while achieving certain goals and also the usability of the applications as well as the participant’s satisfaction after having their first encounter with each version of the application.

5.1.1. Performance Measurement

Based on the global times obtained by the participants we could observe that there were not significant differences between Android and iOS versions. Comparing Titanium and native versions there were some differences (see Table 5.1): two tasks were done faster in the Titanium versions and three in the native versions comparing participants that used each version in the first laboratory test, so we can conclude that in the first time each version was used (with no previous usage of the alternative version), results are comparable. In the usage of each version as the second one used, native versions obtain slightly better results, and global results are better than in the first laboratory test, as expected.
Table 5.1: Global average times for laboratory tests in seconds

<table>
<thead>
<tr>
<th>Task</th>
<th>Titanium version</th>
<th>Native version</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lab. Test 1</td>
<td>Lab. Test 2</td>
</tr>
<tr>
<td>Task 1</td>
<td>25.11</td>
<td>20.15</td>
</tr>
<tr>
<td>Task 2</td>
<td>20.22</td>
<td>14.94</td>
</tr>
<tr>
<td>Task 3</td>
<td>38.61</td>
<td>28.84</td>
</tr>
<tr>
<td>Task 4</td>
<td>24.94</td>
<td>14.05</td>
</tr>
<tr>
<td>Task 5</td>
<td>42.22</td>
<td>38.26</td>
</tr>
</tbody>
</table>

The variation found on times depends on the task but difference of the same task on the same test (Lab. test 1 or Lab. Test 2) is small and not representative. The values obtained mean that on effectiveness terms, both approaches (native or Titanium) generate good final products.

5.1.2. UX Measurement via Questionnaires

5.1.2.1. Titanium Version

The majority of participants identify this version as behaving like a native app, in general terms. From all the participants, 91% of the Android participants and 79% of the iOS participants agree or totally agree with the fact that in general, the application looks and behaves as typical iOS or Android apps. Figures 5.1 and 5.2 illustrate the results obtained in the ad-hoc questionnaire (see Annex D) for iOS and for Android, respectively.

When asked about specific issues, the generic approval rates lower in OS, in particular about the controls and their position on screen, and also about the way of presenting information, since 71% of the iOS participants believe that this version looks as any other application on their platforms with respect to these two concerns.

Figure 5.1: iOS Lab. Test Titanium version.
It is noteworthy that for all the iOS participants (100%) who tested this prototype first, they agree or totally agree that the application looks and behaves as a normal iOS app. However, when the participants used this prototype after using the native one first, only 57% of the participants agree or totally agree with the statement of typical look and behavior in general lines. Figure 5.3 and 5.4 illustrate this information.

On the other hand, on Android the difference between the 1st and the 2nd test is about 2–3%, which is not relevant. These results are illustrated on Figure 5.5 and 5.6.

The satisfaction of the users was measured using the System Usability Scale (SUS), on which this prototype obtained an overall value of 82.7. This value represents that usability of the prototype in general is very good and acceptable.

The evaluated dimensions for the User Experience Questionnaire (UEQ) are: attractiveness, perspicuity, efficiency, dependability and novelty.

The Titanium version for iOS is clear and easy to understand. However, the participants considered that its attractiveness and efficiency are Above Average; its
dependability is Below Average and its novelty is bad. The results are shown on the Table 5.2.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mean</th>
<th>Comparison to benchmark</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>1,131</td>
<td>Above average</td>
<td>25% of results better, 50% of results worse</td>
</tr>
<tr>
<td>Perspicuity</td>
<td>1,75</td>
<td>Good</td>
<td>10% of results better, 75% of results worse</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1,25</td>
<td>Above Average</td>
<td>25% of results better, 50% of results worse</td>
</tr>
<tr>
<td>Dependability</td>
<td>0,857</td>
<td>Below Average</td>
<td>50% of results better, 25% of results worse</td>
</tr>
<tr>
<td>Novelty</td>
<td>-0,017</td>
<td>Bad</td>
<td>In the range of the 25% worst results</td>
</tr>
</tbody>
</table>

On the other hand, the Android users consider that the attractiveness and dependability are Excellent; this version is also clear and easy to understand. Meanwhile, its efficiency is Good and its novelty is Below Average. Results are shown on the Table 5.3.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mean</th>
<th>Comparison to benchmark</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>1,87</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Perspicuity</td>
<td>2,435</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1,543</td>
<td>Good</td>
<td>10% of results better, 75% of results worse</td>
</tr>
<tr>
<td>Dependability</td>
<td>1,87</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Novelty</td>
<td>0,511</td>
<td>Below Average</td>
<td>50% of results better, 25% of results worse</td>
</tr>
</tbody>
</table>

As a summary, the results of both platforms show that the Titanium version is clear and easy to understand, its attractiveness, dependability and efficiency are good; however, the worst result is the novelty dimension, on which the participants expected something completely new or revolutionary in terms of graphical interface and interaction.

5.1.2.2. Native Version

Based on the results, 100% of the iOS participants and 91.30% of the Android participants agree or totally agree that on general terms the application looks and behaves as a typical iOS or Android app. Figures 5.7 and 5.8 show the results obtained with the native version for iOS and for Android, respectively.
During the 1st and 2nd laboratory tests the results do not show a significant difference as shown in Figure 5.9 and Figure 5.10. On the iOS case, the biggest difference is about the way of presenting information. When they tested first this prototype only 85.71% of the participants agree or totally agree that the way of presenting components is natural for this platform; meanwhile, 100% of the participants agree or totally agree with the way of presenting components when they have already tested the Titanium prototype version.

On the other hand, more Android participants agree or totally agree with the statements of natural behaving on general terms, controls, navigation and the way of presenting the information on the 1st laboratory test than on the 2nd laboratory test. In the cases with differences, in the 1st laboratory test the percentage is 10% higher than...
the 2nd laboratory test. Talking about the way of presenting information, in both cases 100% of the participants agree or totally agree that the prototype behaves as a natural Android application. Figure 5.11 and Figure 5.12 illustrate these results.

![Figure 5.11: Android Lab. Test 1](image1)

![Figure 5.12: Android Lab. Test 2](image2)

The evaluation of user satisfaction performed with the System Usability Scale (SUS) overall resulted on a coefficient of 86.82 which means that the prototype has a high degree of usability. It is on the top 10% of scores, which proves that this prototype fulfills the desired usability level and the users are comfortable with it.

Using the User Experience Questionnaire (UEQ), we evaluated the following dimensions: attractiveness, perspicuity, efficiency, dependability and novelty.

For the iOS prototype, the results show that the application is easy to learn and to understand. Its attractiveness, efficiency, and dependability are Excellent meanwhile its novelty is Below Average (which is the worst result from all dimensions). The results are presented on Table 5.4.

### Table 5.4: UEQ Results for iOS - Native prototype version

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mean</th>
<th>Comparison to benchmark</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>2.12</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Perspicuity</td>
<td>2.36</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1.75</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Dependability</td>
<td>1.71</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Novelty</td>
<td>0.43</td>
<td>Below Average</td>
<td>50% of results better, 25% of results worse</td>
</tr>
</tbody>
</table>

The evaluation of the Android prototype is Excellent for its attractiveness, efficiency, dependability, and perspicuity; meaning the application is smooth and easy to use as well as useful. The worst evaluated dimension is novelty, which is considered Good. Table 5.5 contains a summary of the results.
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mean</th>
<th>Comparison to benchmark</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>2.30</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Perspicuity</td>
<td>2.35</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1.86</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Dependability</td>
<td>1.76</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Novelty</td>
<td>1.07</td>
<td>Good</td>
<td>10% of results better, 75% of results worse</td>
</tr>
</tbody>
</table>

According to the summarized results, we can infer that the results the participants considered that the native prototype of the application is totally clear and simple to use for the participants. It is attractive, efficient and they can rely on the app for having a smooth navigation and accessibility to the information. About the prototype’s novelty, the result is just above average.

5.2. Longitudinal Study

The participants completed the longitudinal study surveys after having the application on their own smartphones and testing it on their own for 5 days. The same process was followed with both the Titanium and the native versions.

The interaction between the participants and the applications was recorded and measured using Google Analytics.

5.2.1. UX Measurement via Questionnaires

5.2.1.1. Titanium Version

The perception of 71% of the participants after testing and exploring the app on their own for 5 days is that it looks and behaves in general lines as a typical iOS app; meanwhile, 91% of the Android participants agree or totally agree with the same statement for their platform. Figures 5.13 and 5.14 show the results for the iOS and Android versions of the Titanium prototypes after the 5-day usage period.

The results on both platforms show that there is a significant variation between the values obtained on the first impression (laboratory) test and after 5 days. The results are much lower on iOS when participants are asked about how controls and their position on screen are the typical ones for an iOS app (57% agree), and about the way of presenting information (43% agree).
For the Android prototype, 91% of participants agree or totally agree that the prototype behaves as a typical Android application. Meanwhile, the percentage of participants who agree or totally agree that this prototype’s controls are typical in an Android app is 74%; about the navigation, the result is 65% and according to the way of presenting information is 78%. As it happens on iOS, the values are reduced on 20 to 30 % compared to the values obtained in the first impression (laboratory) test.

The results obtained for both platforms after the 5-day usage period show a significant variation between the values obtained on the first impression test (laboratory) and after 5 days.

For the particular case of iOS platform, the results show that the difference is small between the 1st and 2nd tests. The results mean that the influence of using the Titanium or the native version first on the 5-day usage period was lower. Even though after using the native one first, the perception about the control's position has increased meanwhile in general terms the acceptance has decreased as shown in Figures 5.15 and 5.16.
On Android, the influence of which prototype was used first is also minimal. The differences between the 1st and the 2nd test are small. It is noticeable that the perception in general terms of this version is better when the participants use it after having used the native version as shown in Figure 5.17 and Figure 5.18.

The evaluation of user satisfaction performed with the System Usability Scale (SUS) overall resulted on a coefficient of 82.70. The result is on the top 10% of scores which proves that this prototype fulfills the desired usability level and the users are comfortable with it. These results for SUS are the same than the ones obtained in the laboratory test.

In this case, there is not a big difference between the results from participants who test this version as the first one or as the second one.

Using the User Experience Questionnaire (UEQ), we measured the same dimensions as in the first impression (laboratory) tests.

Table 5.6 shows the information obtained for the evaluated dimensions and the UEQ results of this prototype after 5 days of usage. After completing the free testing period, the participants considered that only the efficiency is Above Average. Its attractiveness and dependability are Below Average; moreover, the perspicuity is Good and as happened on the first impression (laboratory) tests novelty has the worst result being considered Bad.
### Table 5.6: UEQ Results for iOS – Titanium prototype version

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mean</th>
<th>Comparison to benchmark</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>1,024</td>
<td>Below average</td>
<td>50% of results better, 25% of results worse</td>
</tr>
<tr>
<td>Perspicuity</td>
<td>1,696</td>
<td>Good</td>
<td>10% of results better, 75% of results worse</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1,143</td>
<td>Above Average</td>
<td>25% of results better, 50% of results worse</td>
</tr>
<tr>
<td>Dependability</td>
<td>1,036</td>
<td>Below Average</td>
<td>50% of results better, 25% of results worse</td>
</tr>
<tr>
<td>Novelty</td>
<td>-0.339</td>
<td>Bad</td>
<td>In the range of the 25% worst results</td>
</tr>
</tbody>
</table>

On the other hand, the Android participants considered that this version is totally easy to understand and to use having an Excellent perspicuity and Excellent dependability. Its attractiveness is Good, its efficiency above average and the novelty is Below Average.

### Table 5.7: UEQ Results for Android – Titanium prototype version

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mean</th>
<th>Comparison to benchmark</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>1,710</td>
<td>Good</td>
<td>10% of results better, 75% of results worse</td>
</tr>
<tr>
<td>Perspicuity</td>
<td>2,315</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1,304</td>
<td>Above Average</td>
<td>25% of results better, 50% of results worse</td>
</tr>
<tr>
<td>Dependability</td>
<td>1,7609</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Novelty</td>
<td>0.4674</td>
<td>Below Average</td>
<td>50% of results better, 25% of results worse</td>
</tr>
</tbody>
</table>

Having a summary of the results obtained, they show that most of the dimensions have lower qualifications after using the application 5 days than after the first impression tests.

Doing a comparison between these values and the first impression (laboratory) ones, results show that efficiency and attractiveness on the first impression were Good and after using the app for 5 days, the benchmark is Above Average. The perspicuity, dependability and novelty have the same values in both cases. Moreover, the novelty dimension still has the worst results on the test (Bad or Below Average).

#### 5.2.1.2. Native Version

The results of the test show that 100% of the iOS participants and 91% of the Android participants agree or totally agree that this prototype behaves as a typical application of each platform. Figures 5.19 and 5.20 show the results for the iOS version and the Android version of the native prototype after the 5-day usage period, respectively.

On iOS, the values after the 5-day usage period are also 8% lower than the laboratory test on the control's position and the navigation. On the other hand, for the way of presenting information the percentage of users who agree or totally agree that the way of presenting information is the same as a typical iOS application increased on 8%.
For Android, the results of the longitudinal study (after 5-day usage period) and the laboratory test are the same. It means that the prototype behavior is the natural and the expected one for an Android application by the participants.

On the particular case of iOS, the results show that the participants’ perception of the app is better when they tested this application after testing the Titanium one. Even though there is a difference, it is not really high and in some aspects like the way of presenting information the values are the same in both cases. Figure 5.21 and Figure 5.22 illustrate the information obtained.

For the Android case, the results obtained show a better evaluation when the participants tested this application first. When they knew already the Titanium version,
the acceptance of this version decreases meaning that the Titanium version has impacted on the participants. The most significant difference appears on the navigation through the screens where the difference is high in the 2nd test; it indicates that addressing this subject, there are clear differences between the interaction design of the Titanium and the native versions. Figure 5.23 and Figure 5.24 illustrate the obtained results.

<table>
<thead>
<tr>
<th>Figure 5.23: Android Longitudinal Test 1</th>
<th>Figure 5.24: Android Longitudinal Test 2</th>
</tr>
</thead>
</table>

In terms of usability, the evaluation of this prototype on the System Usability Scale (SUS) resulted on a coefficient of 89.12. This result is on the 10% top scores of the scale and comparable to the value obtained in the first impression evaluation, which is 86.82. From these results it can be inferred that the satisfaction of the users increased when they could explore the application by themselves.

The results obtained and the dimensions evaluated using the UEQ questionnaire show that in both platforms the perception of the participants with the native prototype version of the application is that the application behaves as a native one in general lines, having Excellent rating on several dimensions.

In the iOS case, the participants consider that the application is smooth, fluid and understandable. Its attractiveness, perspicuity and dependability are Excellent. The efficiency is Good; however, the novelty is Below Average having the worst evaluation of all dimensions. Table 5.8 shows the values obtained for the iOS native version.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mean</th>
<th>Comparison to benchmark</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>1.988</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Perspicuity</td>
<td>3.125</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1.464</td>
<td>Good</td>
<td>10% of results better, 75% of results worse</td>
</tr>
<tr>
<td>Dependability</td>
<td>1.786</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Novelty</td>
<td>0.607</td>
<td>Below Average</td>
<td>50% of results better, 25% of results worse</td>
</tr>
</tbody>
</table>

For the Android case, the results are almost the same as the iOS on which are highlighted the attractiveness, perspicuity and dependability and evaluated as Excellent. The efficiency of the app is considered as Good and its novelty is Above Average. In this case, the novelty dimension has a better result the iOS version. Table 5.9 shows the results of the dimensions measured on the UEQ questionnaire.

Table 5.8: UEQ Results for iOS – Native prototype version

Table 5.9: UEQ Results for Android – Native prototype version
### Table 5.9: UEQ Results for Android – Native prototype version

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Mean</th>
<th>Comparison to benchmark</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attractiveness</td>
<td>2,246</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Perspicuity</td>
<td>3,304</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Efficiency</td>
<td>1,543</td>
<td>Good</td>
<td>10% of results better, 75% of results worse</td>
</tr>
<tr>
<td>Dependability</td>
<td>1,783</td>
<td>Excellent</td>
<td>In the range of the 10% best results</td>
</tr>
<tr>
<td>Novelty</td>
<td>1,065</td>
<td>Above Average</td>
<td>25% of results better, 50% of results worse</td>
</tr>
</tbody>
</table>

As a summary, the results obtained on the attractiveness, perspicuity, dependability and novelty have the same benchmark value as the first impression of the participants. In the case of perspicuity the numeric value is better after using the application for 5 days. However, in the case of efficiency, the values are lower than the first impression tests. The results can be based on the fact that the users have more time to explore all the functionalities of the application on a real environment and maybe find some flaws. The novelty dimension has the same result as the first impression tests.

#### 5.2.2. Google Analytics

The information retrieved by Google Analytics was useful to understand and control the use of the applications during the 5-day usage period. This data joined with the answers of the questionnaires allows a better interpretation of the usage and the interaction between the application and the users in a real environment during real situations.

##### 5.2.2.1. Titanium Version

Based on the information recorded with Google Analytics, the average session time of each user during the free testing period was 01:55 minutes and the participants have viewed 7,72 screens per session.

Most of the participants have used the application during the 5-day usage period having 85.4% of them as recurrent users. The percentage of new sessions is 14.63%. Figure 5.25 illustrated the users’ distribution.
The five most visited screens are: the home screen, the bus lines list screen, the bus line detail screen, the news list screen and next buses screen. This information confirms the facts mentioned by the participants that the most useful module was the buses module. However, from the mentioned five screens the participants have spent more time on the news window than on the other ones having an average time of 00:34 seconds.

The application was installed successfully and used without any major issue (crashes or functionality problems) on several OS versions of iOS and Android in several devices. Figure 5.26 illustrates this information.

![OS versions](image)

**Figure: 5.26: OS versions**

### 5.2.2.2. Native Version

For the native version, the average session time of each user during the free testing period was 01:50 minutes and the participants have viewed 9.41 screens per session.

Most of the participants have used the application during the 5-day usage period having 93.2% of them as recurrent users; the percentage of new sessions is 6.82%. Figure 5.27 illustrated the users’ distribution.

![users_distribution](image)

**Figure 5.27: Users’ sessions tendency Native version.**

The five most visited screens are: home screen, news list screen, bus line screen, staff list screen and open specific news screen. In this case, the tendency is almost the same as in the Titanium version; the buses module is the most used one. However, it is remarkable that in the native version prototype, the participants used more the staff module than in the Titanium prototype.
The application was installed in several versions of iOS and Android using different mobile devices. The application ran smoothly, fluently and without any major issues (crashes or functionality problems) on all those versions. Figure 5.28 illustrated the percentage of each OS in the participants’ mobile devices.

**Figure: 5.28: OS versions**

### 5.3. Final comparison evaluation

After using and testing every version of the app for five days, participants were asked to compare both applications and choose which option suits better to their idea of an iOS or Android application. Figure 5.29 and Figure 5.30 illustrate the answers and the preferences for iOS and Android participants, respectively.

On iOS, users clearly prefer the native version to the Titanium one as typical iOS app (79%+7% preferring native version vs. 7% preferring Titanium version).

**Figure: 5.29: iOS participants’ prototype preferences**

However, on Android the difference is smaller (35%+17% preferring native version vs. 13%+26% preferring Titanium version).
Considering the global results (see Figure 5.31), 51% of participants think that the native version suits better than the Titanium version to their idea of a typical app for their platform, plus 14% who think that it suits somehow better, as opposed to 27% who think the contrary, and 8% who think both versions fit into their idea of a typical app in their platform.

5.4. Threats to validity

As a threat to the validity of the results, there is the issue of design decisions affecting the UX. In this case, we balanced the usability expertise between the two independent development teams who have worked on the applications.
Each development team had a usability expert member who was in charge of coordinating the design and implementation activities. Both development teams have worked independently having complete autonomy when making design or coding decisions. The only thing both teams had in common were the requirements for the functionalities the mobile application had to offer. This independence may generate notorious differences on the interaction or how the functionalities are designed.

Even though all the concerns and the considerations taken into account, there can always be individual differences that affect the quality of each design solution. Given that users scored highly both versions of the app in terms of usability, we expect to have been successful in limiting the impact of this question into validity.

5.5. Analysis

The native versions obtained better results than the cross-platform ones and the results show an existing difference in terms of usability and UX. In the following paragraphs, the results are analyzed in detail showing the tendency and the preferences of the participants in the study for both platforms (iOS and Android).

The differences between the results of the laboratory tests on iOS with both prototypes, (see Figure 5.1 and Figure 5.7), with a higher assessment of the native version as a typical iOS app, are probably caused by the known fact of iOS platform having higher homogeneity between apps than Android. Due to this homogeneity, users expect certain specific behaviors or interactions and probably Titanium does not make such a good job as a usability expert in keeping the interaction design aligned with platform conventions.

It is remarkable to mention that on iOS, the evaluation of the Titanium prototype was affected by the influence produced of using the native prototype first (see Figure 5.3 and Figure 5.4). After having experience with the native version, the participants consider that the Titanium prototype does not behave in general terms as an iOS application. The same perception happens with the way of presenting information and about the control's position; talking about the navigation, the results are very similar when asked in abstract if the app behaves as a typical iOS app, results are higher than when the users have had a concrete app to compare with.

On Android, the results of the laboratory tests are almost the same or have a small variation (see Figure 5.2 and Figure 5.8). Having a detailed look to the values obtained on the first impression tests, the results show that testing first the Titanium or the native application has not influenced the participants' point of view about the prototypes (see Figure 5.5 and Figure 5.6). Their perception is that the native version and the cross-platform one behave as natural as any other Android application and the user experience generated is very good, fulfilling their expectations.

The longitudinal study results show a stronger preference for the native version, which is again higher between iOS users than between Android users after using the app for 5 days (see Figure 5.13 and Figure 5.19). Moreover, the perception on Android is the same as the laboratory studies; both the cross-platform and the native application have similar results meaning that the interaction on both emulates a native Android app (see Figure 5.14 and Figure 5.20).

Regarding the usability of the application measured with the SUS questionnaire, the participants' perception is to consider native version better than the cross-platform version but the difference is not too big. Most of the results (laboratory and longitudinal
studies) are on the 10% top scores of the SUS scale. In this case, the tendency is that results after the 5-day usage period are better than the ones from the first approach. These values may mean that the application is useful for the participants and has helped them to solve specific problems or helped on a student daily life.

About the satisfaction of the users measured with UEQ questionnaire, in both cases, after the 5-day usage period, the results are lower than the participant’s first impression. This may be caused because during the 5-day usage period, the users were able to explore the different options of the application on their own and also use it under real circumstances, which can cause a change in their perception as they found it difficult to use or not so much attractive any more. Even with the mentioned variation on the results, the tendency remains as the native versions obtained higher marks than the framework-generated ones.

There are important differences between the results obtained by the Titanium and the native versions of the application on iOS (see Table 5.2 and Table 5.4) on the laboratory test; the same differences were found in the longitudinal study (see Table 5.6 and Table 5.8). These differences on the evaluations are caused due to the fact of pre-conceived ideas about how an iOS application should interact, its response times and its navigation. The perception and impressions generated by the native version are very high and its results are better results than the Titanium one.

On the other hand, for the Android case (see Table 5.3 and Table 5.5) the evaluation is similar for both versions. With slightly better results or the native version, the same tendency remains on the evaluation done for the longitudinal study (see Table 5.7 and Table 5.9). The participants consider that both versions are smooth, fluid, easy to understand and useful. The margin of difference between the native and the Titanium version is low. In fact, both applications excel on the dependability and perspicuity dimensions in both studies (first impression and longitudinal). The application generated on both cases adapts to the idea of an Android application.

In the results of the questionnaire where participants are asked to compare directly the native version vs. the Titanium one, it is where the preference for the native version is shown more clearly. In this respect, there are important differences between iOS and Android users (see Figure 5.29 and Figure 5.30): iOS users clearly prefer the native version to the Titanium one as typical iOS app (86% vs. 7%); in Android the difference is much smaller (52% vs. 39%). A possible factor for this difference between platforms could be that some Android participants preferred the functionalities offered on the Titanium version to the ones present in the native version. On the contrary, iOS versions did not have such differences in functionality; therefore iOS participants did not mention differences in functionality as the reason for their preference for the native version.

The information obtained on Google Analytics was used to confirm the tendencies and the answers of the participants about the usage of the application under real circumstances for 5 days. The data shows that the participants have used regularly the application; they have tried several features and options being the most used feature the buses module. These results confirm the answers on the questionnaires on which were stated as the most used functionalities were the buses and the news modules.

The final results and the observations in this study go in the same line as the results obtained in [Humayoun et al., 2013] in general terms, even if such work presents a more limited evaluation.
Finally, we can say that there appears to be some evidence that the usage of a cross-platform development framework, even when considering the one available that provides a better support in terms of particularizing for the specific UX of each platform, affects negatively to the UX of the resulting app. The effect is notorious for the iOS platform, probably due to the higher degree of homogeneity between iOS apps. For Android, this effect also appears but its impact is relatively low. The exact quantification of this negative effect would require further experimentation.
6. Conclusions and Future work

6.1. Introduction

Having completed the usability study and analyzing the results obtained after performing the tests with participants, on this section are stated the conclusions obtained, as well as the different opportunities identified for future work on this topic.

6.2. Conclusions

We have carried out a case study to evaluate how the decision to develop a mobile app using use a cross-platform framework impacts the UX of the resulting app, against developing with native code for each platform considered.

The advantages of cross-platform frameworks from a development point of view are well known, and they are the main reason behind their popularity, but in this work it has been evaluated in terms of the UX of the produced application with both a laboratory test and a longitudinal study, with an application that has enough functionality to be considered a full-scale app, and with a number of test participants to provide a minimum coverage of the two main mobile platforms: Android and iOS.

The final product generated by developing an application with cross-platform frameworks can generate smooth and fluid applications for both platforms (iOS and Android), which can adapt almost completely and use most of the hardware features. But depending on the nature of the project and the usability level desired, extra libraries or extra components would be required as part of the development for being able to adapt and obtain the best benefits of the targeted platforms, as well as offering a better UX for the users.

It is not accurate to think that the cross-platform approach means that the same code works automatically for all the different platforms or different devices. It is true that most of the code can be reused, but it also requires customizations in some cases. Depending on several factors like nature of the project or the targeted platform, some particular features, functionalities or interactions have to be programmed specifically for a determined platform.

As mentioned, cross-platform frameworks can be a good solution for developing applications and targeting several platforms. The main issue is selecting the framework that suits the best to the nature of the project and the platform.

The results of the study show that a good level of UX can be obtained if the cross-platform development framework is chosen carefully in terms of providing adapted interaction styles for each platform, and the development team has UX expertise. But there are more possibilities of getting a better UX by developing a native application, because of how it allows maintaining the control over interaction issues. These results are stronger for the iOS platform than for the Android one, where users may be accustomed to a higher diversity of interaction styles.

The differences found on the participants’ usability impressions of the application are caused due to the fact of allowing the users to explore and navigate through the application independently. On the first impression, the testing conditions are controlled and the interaction between the participants and the app are already established.
Meanwhile, during the free testing period the users can do unexpected things, which can lead participants to form a more accurate impression of the app characteristics.

According to the results, the native version of our app was more accepted by the iOS and Android participants. This perception is shown on the satisfaction questionnaires and on the final comparison evaluation. The results are explained due to the fact of having differences between the versions and the interaction as different teams developed both apps. It is remarkable to mention that on Android, some functionality was preferred on the cross-platform version than on the native ones.

6.3. Future lines of research

Further research is needed to tackle the specific interaction design issues that will be difficult to cover in the framework-generated apps, in order to help the design teams using them, and to establish a framing theory that offers software engineers a way of weighting the advantages offered by these tools from a development point of view, with the possible loss in overall product quality that a lesser UX implies.

Additional possible promising lines of research are:

- **To experiment on other domains.** Performing an experiment to test other applications considering different domains and different nature of the projects can contribute for having more information about a comparison between native and cross-platform mobile applications. Also this research can provide information about the influence on UX terms that the development approach used has on users.

- **To compare different cross-platform frameworks.** This study used one of the cross-platform frameworks available on the market and performing a comparison of other different frameworks available will allow quantifying the effect of UX on applications developed using cross-platform frameworks.

- **To provide guidelines of customization to generate a better UX.** As mentioned above, certain features of the applications require having specific code or customize the options provided by the cross-platform frameworks to achieve the desired functionality and user experience to the developers concerned about the usability and UX on mobile applications. The objective is to generate guidelines for being able to customize the options offered by the frameworks. Having guidelines and baselines for helping the development process and also to highlight the points concerning to UX which have to be taken into account at the moment of developing a mobile app for different platforms.

- **To extend the functionality of mobile cross-platform frameworks.** Studying how to extend cross-platform frameworks to improve them in terms of usability and UX. This improvement would look forward to give developers better tools for being able to create successfully a mobile application for different platforms with a high level of usability and UX.
References


Case Study on Mobile Applications UX: Effect of the Usage of a Cross-Platform Development Framework


ANNEX A: Usability test questionnaire for the first version of the cross-platform prototype

This questionnaire was designed to register the impressions of the testers for being able to improve the design and the cross-platform prototype. The questionnaire has four sections to recover the personal information and the behavior of the test participants towards the mobile platforms, the evaluation of the tasks, the general evaluation of the prototype, and some specific questions to obtain participants’ impressions about the prototype.

Datos personales

Edad: _____ años
Género: [ Varón ] [ Mujer ]

En julio de 2013 hicimos un test de usabilidad con una versión preliminar de la app de la FIUPM ¿participaste en ese test de usabilidad? _____

¿Qué relación tienes con la Facultad de Informática?:
○ Soy estudiante de Grado
○ Soy estudiante de Máster
○ Soy profesor
○ Soy personal de administración y servicios (PAS)
○ Soy investigador no incluido en ninguna de las categorías anteriores

¿Cuántos años llevas estudiando o trabajando en la Facultad de Informática?: _____ años

Modelo del móvil que usas habitualmente:
_________________________________________
Sistema operativo del móvil: ______________________ con la versión:
_________________

¿Cuánto tiempo llevas utilizando esa plataforma?
○ Menos de 6 meses
○ Entre 6 meses y 1 año
○ Entre 1 año y 2 años
○ Más de 2 años

¿Cuánto tiempo al día usas tu teléfono?
○ Menos de 1 hora
○ Entre 1 y 2 horas
○ Entre 2 y 4 horas
○ Más de 4 horas
¿Para qué usas el móvil habitualmente?

1. ________________________________________________________________

2. ________________________________________________________________

3. ________________________________________________________________

¿Con qué frecuencia accedes a la web de la Facultad desde el móvil?

- Más de una vez al día [___]
- Alrededor de una vez al día [___]
- Entre una y cuatro veces por semana [___]
- Varias veces al mes [___]
- Menos de una vez al mes [___]
- Nunca [___]

¿Para buscar qué información?

- Encontrar información concreta con respecto a tus estudios [___]
- Mirar los horarios de los autobuses [___]
- Ver las noticias/eventos/anuncios/avisos [___]
- Ver el menú del día de la cafetería [___]
- Ver información de contacto de un profesor o información de un aula concreta [___]
- Otros: ___________________________________________________________ [___]
## Evaluación de las tareas pedidas

Valora de 1 a 5 las siguientes afirmaciones, donde 1 significa “muy difícil” y 5 significa “muy fácil”.

<table>
<thead>
<tr>
<th></th>
<th>Muy difícil</th>
<th>Difícil</th>
<th>Indiferente</th>
<th>Fácil</th>
<th>Muy fácil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Me ha resultado intuitivo compartir una noticia con mis conocidos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>He encontrado rápidamente el horario de la oficina internacional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Me ha resultado sencillo encontrar los datos de un profesor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>La opción de guardar un contacto en el teléfono estaba donde esperaba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>La opción de añadir un evento al calendario estaba donde esperaba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Evaluación general de la aplicación**

Valora de 1 a 5 las siguientes afirmaciones, donde 1 significa “estoy en completo desacuerdo” y 5 significa “estoy totalmente de acuerdo”.

<table>
<thead>
<tr>
<th></th>
<th>Estoy en completo desacuerdo</th>
<th>No estoy de acuerdo</th>
<th>Indiferente</th>
<th>Estoy de acuerdo</th>
<th>Estoy totalmente de acuerdo</th>
</tr>
</thead>
<tbody>
<tr>
<td>La aplicación permite realizar las tareas solicitadas de forma fácil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>La navegación entre las opciones resulta clara</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>La apariencia general del producto es agradable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Los iconos que aparecen en la interfaz de la aplicación son representativos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Los nombres de las opciones me han parecido claros y representativos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Me ha sido fácil encontrar la información que buscaba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>En general la aplicación me parece fácil de usar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cuando la aplicación esté disponible la usaré a menudo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Esta aplicación me da acceso a la información que normalmente consulto en la web de la facultad</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cuestionario de Impresiones

Responde brevemente las siguientes preguntas

1. ¿Cuáles son los principales problemas que has encontrado al usar este producto?

2. ¿Cuáles son las características (positivas) más destacables para ti?

3. ¿Cuál es la parte del sistema que crees que es la más oscura o difícil de entender?

4. ¿Puedes describir tu experiencia general al usar el producto?

5. ¿Has echado en falta alguna funcionalidad en la aplicación? ¿Tienes alguna sugerencia para mejorarla?
ANNEX B: SUS Questionnaire

This questionnaire was applied to the participants in the laboratory tests and after the 5-days usage period of the longitudinal study. It was applied in Spanish and its original version can be found in [Brook, 1996].

**SUS**

*Indica tus impresiones del sistema que acabas de probar*

Por favor, seleccione la respuesta apropiada para cada concepto:

<table>
<thead>
<tr>
<th>Preguntas</th>
<th>Totalmente en desacuerdo</th>
<th></th>
<th></th>
<th></th>
<th>Totalmente de acuerdo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creo que me gustaría usar este sistema frecuentemente</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encontré el sistema innecesariamente complejo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pienso que el sistema fue fácil de utilizar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creo que necesitaría apoyo de un experto para utilizar este sistema</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encontré las diversas funcionalidades del sistema bastante bien integradas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pienso que hay demasiada inconsistencia en este sistema</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Creo que la mayoría de la gente podría usar este sistema rápidamente</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>He encontrado el sistema bastante incómodo de utilizar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Me he sentido muy seguro haciendo uso del sistema</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Necesitaría aprender muchas cosas antes de poder utilizar el sistema</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ANNEX C: UEQ Questionnaire

This questionnaire was applied to the participants in the laboratory tests and after the 5-day usage period of the longitudinal study. The authors provide a Spanish translation of the questionnaire as well as the original English version in [UEQ, 2014]. Some questions were removed from the original version because they did not apply to the particular context of this study.

UEQ

Por favor, indica para cada fila de la siguiente tabla cuál es tu impresión del sistema. En cada fila aparecen dos términos opuestos en los extremos, indica el punto que refleja cuán cerca o lejos está tu valoración del sistema con respecto a esos extremos.

Por favor, seleccione la respuesta apropiada para cada concepto:

<table>
<thead>
<tr>
<th>Concept</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>desagradable</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>agradable</td>
</tr>
<tr>
<td>no entendible</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>entendible</td>
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<td>creativo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sin imaginación</td>
</tr>
<tr>
<td>fácil de aprender</td>
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<td></td>
<td></td>
<td></td>
<td>difícil de aprender</td>
</tr>
<tr>
<td>impredecible</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>predecible</td>
</tr>
<tr>
<td>original</td>
<td></td>
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<td></td>
<td></td>
<td>convencional</td>
</tr>
<tr>
<td>obstructivo</td>
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<td></td>
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<td></td>
<td></td>
<td>impulsor de apoyo</td>
</tr>
<tr>
<td>bueno</td>
<td></td>
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<td></td>
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<td></td>
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<td>malo</td>
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<tr>
<td>complicado</td>
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<td>fácil</td>
</tr>
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<td>atraer</td>
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<td>novedoso</td>
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<tr>
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<td>cómodo</td>
</tr>
<tr>
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<td></td>
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<td></td>
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<td>feo</td>
</tr>
<tr>
<td>simpático</td>
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<td></td>
<td></td>
<td></td>
<td>antipático</td>
</tr>
<tr>
<td>conservador</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>innovador</td>
</tr>
</tbody>
</table>
ANNEX D: Ad-hoc Questionnaire for Laboratory Usability Tests

This questionnaire was designed to obtain the impressions and the feelings about the prototypes compared to other applications on the mobile platform used by the participant. It was applied in Spanish after the laboratory test for each of the versions of the application.

Cuestionario Específico

Estas preguntas son para conocer tus impresiones específicas sobre la aplicación.

1 ¿Qué aplicación acabas de utilizar? *

Por favor seleccione sólo una de las siguientes opciones:

☐ A

☐ B

2 ¿Qué plataforma utilizas? *

Por favor seleccione sólo una de las siguientes opciones:

☐ iOS

☐ Android

3 ¿La aplicación que acabas de usar tiene el aspecto y se comporta como una aplicación iOS típica? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: Plataforma utilizada es iOS.

Por favor, seleccione la respuesta apropiada para cada concepto:

<table>
<thead>
<tr>
<th></th>
<th>Totalmente en desacuerdo</th>
<th>En desacuerdo</th>
<th>Indiferente</th>
<th>De acuerdo</th>
<th>Totalmente de acuerdo</th>
</tr>
</thead>
<tbody>
<tr>
<td>En general</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a los controles y su posicionamiento en la pantalla</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a la forma de navegar entre las distintas pantallas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a la forma de presentación de la información</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4 ¿La aplicación que acabas de usar tiene el aspecto y se comporta como una aplicación Android típica? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: **Plataforma utilizada es Android.**

Por favor, seleccione la respuesta apropiada para cada concepto:

<table>
<thead>
<tr>
<th></th>
<th>Totalmente en desacuerdo</th>
<th>En desacuerdo</th>
<th>Indiferente</th>
<th>De acuerdo</th>
<th>Totalmente de acuerdo</th>
</tr>
</thead>
<tbody>
<tr>
<td>En general</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a los controles y su posicionamiento en la pantalla</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a la forma de navegar entre las distintas pantallas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a la forma de presentación de la información</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ANNEX E: Ad-hoc Questionnaire for Longitudinal Usability Tests

This questionnaire was designed to obtain the impressions and the feelings about the prototypes compared to other applications on the mobile platform used by the participant. It was applied in Spanish after the 5-day usage period of the longitudinal study for each of the versions of the application.

Cuestionario Específico

Estas preguntas son para conocer tus impresiones específicas sobre la aplicación.

1 ¿Qué aplicación acabas de utilizar? *

Por favor seleccione sólo una de las siguientes opciones:

- O A
- O B

2 ¿Qué plataforma utilizas? *

Por favor seleccione sólo una de las siguientes opciones:

- O iOS
- O Android

3 ¿La aplicación que acabas de usar tiene el aspecto y se comporta como una aplicación iOS típica? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: Plataforma utilizada es iOS.

Por favor, seleccione la respuesta apropiada para cada concepto:

<table>
<thead>
<tr>
<th></th>
<th>Totalmente en desacuerdo</th>
<th>En desacuerdo</th>
<th>Indiferente</th>
<th>De acuerdo</th>
<th>Totalmente de acuerdo</th>
</tr>
</thead>
<tbody>
<tr>
<td>En general</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Respecto a los controles y su posicionamiento en la pantalla</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Respecto a la forma de navegar entre las distintas pantallas</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Respecto a la forma de presentación de la información</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
</tr>
</tbody>
</table>
4 ¿La aplicación que acabas de usar tiene el aspecto y se comporta como una aplicación Android típica? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: Plataforma utilizada es Android.

Por favor, seleccione la respuesta apropiada para cada concepto:

<table>
<thead>
<tr>
<th></th>
<th>Totalmente en desacuerdo</th>
<th>En desacuerdo</th>
<th>Indiferente</th>
<th>De acuerdo</th>
<th>Totalmente de acuerdo</th>
</tr>
</thead>
<tbody>
<tr>
<td>En general</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a los controles y su posicionamiento en la pantalla</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a la forma de navegar entre las distintas pantallas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respecto a la forma de presentación de la información</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5 ¿Cuántas veces has usado la aplicación en estos 5 días? *

Por favor, escriba su respuesta aquí:

6 ¿Qué funciones has utilizado? (respuesta múltiple) *

Por favor, marque las opciones que correspondan:

- [ ] Noticias
- [ ] Anuncios
- [ ] Eventos
- [ ] Avisos
- [ ] Autobuses
- [ ] Directorio de Personal
- [ ] Asignaturas
Cuestionario Específico de Funcionalidades

Las siguientes preguntas buscan entender por qué no utilizaste todas las funcionalidades de la aplicación.

7 ¿Por qué no has utilizado Noticias? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: No haber seleccionado Noticias en la pregunta anterior

Por favor seleccione sólo una de las siguientes opciones:

- Porque no me interesaba
- Porque no sabía que era
- Otro

8 ¿Por qué no has utilizado Anuncios? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: No haber seleccionado Anuncios en la pregunta anterior

Por favor seleccione sólo una de las siguientes opciones:

- Porque no me interesaba
- Porque no sabía que era
- Otro

9 ¿Por qué no has utilizado Eventos? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: No haber seleccionado Eventos en la pregunta anterior

Por favor seleccione sólo una de las siguientes opciones:

- Porque no me interesaba
- Porque no sabía que era
- Otro

10 ¿Por qué no has utilizado Avisos? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: No haber seleccionado Avisos en la pregunta anterior
Por favor seleccione sólo una de las siguientes opciones:

- Porque no me interesaba
- Porque no sabía que era
- Otro

11 ¿Por qué no has utilizado Autobuses? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones:
No haber seleccionado Autobuses en la pregunta anterior

Por favor seleccione sólo una de las siguientes opciones:

- Porque no me interesaba
- Porque no sabía que era
- Otro

12 ¿Por qué no has utilizado Directorio de Personal? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones:
No haber seleccionado Directorio de Personal en la pregunta anterior

Por favor seleccione sólo una de las siguientes opciones:

- Porque no me interesaba
- Porque no sabía que era
- Otro

13 ¿Por qué no has utilizado Asignaturas? *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones:
No haber seleccionado Asignaturas en la pregunta anterior

Por favor seleccione sólo una de las siguientes opciones:

- Porque no me interesaba
- Porque no sabía que era
- Otro
ANNEX F: Ad-hoc Final Comparison Questionnaire

This questionnaire was designed to obtain the impressions of the participants comparing the two versions of the application that they have tested. This questionnaire was applied just once to the participants and only after finishing both laboratory tests and both 5-day usage periods.

Evaluación del Comportamiento de la Aplicación

1 ¿Qué plataforma utilizas? *

Por favor seleccione sólo una de las siguientes opciones:

☐ iOS

☐ Android

2 Por favor evalúa las aplicaciones que has probado *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: Plataforma utilizada es iOS.

Por favor, seleccione la respuesta apropiada para cada concepto:

<table>
<thead>
<tr>
<th>¿Qué versión de la aplicación crees que responde mejor a tu idea de lo que es una aplicación iOS?</th>
<th>La aplicación A es la que mejor encaja</th>
<th>La aplicación A encaja algo mejor</th>
<th>Las dos por igual</th>
<th>La aplicación B encaja algo mejor</th>
<th>La aplicación B es la que mejor encaja</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
3 Por favor evalúa las aplicaciones que has probado *

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: **Plataforma utilizada es Android.**

Por favor, seleccione la respuesta apropiada para cada concepto:

<table>
<thead>
<tr>
<th>La aplicación A es la que mejor encaja</th>
<th>La aplicación A encaja algo mejor</th>
<th>Las dos por igual</th>
<th>La aplicación B encaja algo mejor</th>
<th>La aplicación B es la que mejor encaja</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

¿Qué versión de la aplicación crees que responde mejor a tu idea de lo que es una aplicación Android?

4 ¿Hay algún elemento o comportamiento de la app que no haya funcionado o no se haya mostrado como esperabas? *

Por favor seleccione sólo una de las siguientes opciones:

☐ Sí
☐ No

5 ¿Qué elemento o comportamiento de la aplicación no ha funcionado o no se ha mostrado como esperabas y por qué?

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: **La respuesta a la pregunta 4 es Sí.**

Por favor, escriba su respuesta aquí:
6 ¿Cuál es tu impresión general sobre la aplicación en comparación con las otras Apps de iOS que usas habitualmente?. Si encuentras algo que te parezca raro indícalo aquí:

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: **Plataforma utilizada es iOS**.

Por favor, escriba su respuesta aquí:


7 ¿Cuál es tu impresión general sobre la aplicación en comparación con las otras Apps de Android que usas habitualmente?. Si encuentras algo que te parezca raro indícalo aquí:

Sólo conteste esta pregunta si se cumplen las siguientes condiciones: **Plataforma utilizada es Android**.

Por favor, escriba su respuesta aquí:


