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Contributions to Web Accessibility: Device-tailored Evaluation, User-tailored Interface Generation and the Interplay with User Experience

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To my wonderful parents.

"The noblest pleasure is the joy of understanding."

Leonardo da Vinci (1452 - 1519)

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Abstract

The Web has an incredible importance in our modern society and for many people it has become a fundamental part of their lives. It enables us to access a huge amount of information, and use a wide range of services related to diverse areas of our daily activities, which has the potential of making our lives easier. Its ubiquitous nature and advances in mobile devices have led to the possibility of accessing the Web any time and from anywhere. This has numerous and obvious advantages, but at the same time it poses challenges related to the Universal Design (UD), as websites need to adapt to the existing diversity of users, devices and interaction contexts. For instance, to ensure the accessibility of a website, in addition to the human diversity, the features of the existing computing devices with access to the Internet, as well as features of the environment where the interaction will occur have to be considered. Similarly, this information can be used when checking the accessibility of websites, so that evaluations are closer to what users are really experiencing when accessing the websites.

In this thesis a device tailored web accessibility evaluation framework and an automated web-based user tailored interface generator are presented. The evaluation framework deals with device specific information. Empirical data showed that more accurate and reliable accessibility reports are obtained in comparison to performing evaluations that do not consider device specific information. The interface generator takes into consideration information about users and their interaction context, in order to adapt web-based user interfaces. From the conducted case study it was concluded that the automatically generated user tailored user interfaces were fully operable. These two tools can be of great help for web developers to create and maintain accessible content for a wide range of users and interaction contexts.

Accessible and adapted user interfaces do not necessarily provide users with an enhanced experience though. With the aim of investigating how accessible user interfaces influence the experience of users and understanding if accessibility is related to a better user experience, a user testing was conducted. In order to investigate this relationship, data from 11 participants was elicited about their subjective accessibility perceptions and their user experience with four websites with different levels of accessibility. Results showed that participants' user experience and their perceived web accessibility are closely related. In addition, web accessibility is correlated to three attributes (typical - original, conservative - innovative, lame - exciting) of the hedonic quality stimulation dimension of the user experience. These findings provide the web community with additional knowledge about the interactions between the user experience and web accessibility.

Laburpena

Web-ak izugarrizko garrantzia dauka gure gaur egungo gizartean, eta persona askorentzat beraien bizitzan funtsezkoa bihurtu da. Web-ak informazio kantitate handirako atzipena eta eguneroko ekintzekin erlazionatutako zerbitzu anitz erabiltzea ahalbidetzen du, beraz gure bizitza errazteko ahalmena dauka. Bere nonahiko izaerak eta gailu mugikorretan gertatu diren aurrerakuntzek, Web-a edozein momentutan eta edozein lekuan atzitzeko aukera eragin dute. Honek abantai anitz ditu, baina aldi berean Diseinu Unibertsalarekin zerikusia duten erronkak sortzen ditu. Adibidez, webgune baten irisgarritasuna ziurtatzeko, pertsonen aniztasunaz gain, Interneterako atzipena duten dispositiboen eta elkarrekintza gertatzen den inguruaren ezaugarriak hartu behar dira kontuan. Informazio hori ere erabili daiteke web guneen irisgarritasuna ebaluatzeko, era honetan ebaluazioek, erabiltzaileak web gunea atzitzerakoan duten esperientzarekin antza gehiago izango dute.

Tesi honetan, web irisgarritasuna dispositibo mugikorren arabera ebaluatzen duen tresna bat eta erabiltzailei egokitzen diren Web-ean oinarritutako interfazeak automatikoki sortzen dituen sistema bat aurkezten dira. Ebaluazio tresnak dispositibo mugikorren ezaugarrien informazio espezifikoa erabiltzen du. Datu enpirikoen arabera, irisgarritasun ebaluazio txostenak zehatzagoak eta fidagarriagoak dira dispositibo mugikorren inguruko informazio espezifikoa erabiltzen bada irisgarritasun ebaluazioetan. Interfazeak sortzen dituen sistemak, erabiltzaileen eta elkarrekintza gertatzen den inguruneko informazioa erabiltzen du. Burututako ikerketa kasu baten emaitzen arabera, sistemak sortutako erabiltzaileei egokitutako interfazeak guztiz funtzionalak zirela ondorioztatu zen. Bi tresna hauek, eduki irisgarria mantentzeko eta sortzeko oso lagungarriak izan daitezke web garaitzaileentzat. Batez ere erabiltzaile anitz eta elkarrekintza ingurune desberdin ugari existitzen direla kontuan izanda. Interface irisgarri eta egokituek ordea, ez dute beti erabiltzaileen esperientzia hobetzen. Interfaze irisgarriek erabiltzaileen esperientzian duen eragina ikertzeko, eta

ea irisgarritasuna erabiltzaileen esperientziaren hobekuntzarekin erlazionatuta dagoen ulertzeko, erabiltzaile proba bat burutu zen. Hamaika erabiltzaileen irisgarritasun pertzepzioa eta erabiltzaile esperentzia aztertu ziren lau web gune ezberdinen inguruan, gune bakoitzak irisgarritasun maila ezberdin bat zuelarik. Emaitzen arabera, erabiltzaileen esperientzia eta irisgarritasun pertzepzioa oso lotuta daude. Gainera web irisgarritasuna, erabiltzaile esperientziaren hiru atributuekin (antigoaleko - original, atzerakoi - berritzaile, aspergarri - interesgarri) erlazionatuta dagoela ikusi zen. Emaitza hauek, web irisgarritasunaren eta erabiltzaile esperientziaren arteko erlazioari buruzko ezagutza gehitzen du web komunitatera.

Resumen

La Web tiene una importancia increíble en nuestra sociedad moderna, y para muchas personas se ha convertido en una parte fundamental de sus vidas. Nos posibilita el acceso a una gran cantidad de información, y el uso de un gran abanico de servicios relacionados con diversas áreas de nuestras actividades diarias, lo que tiene el potencial de hacernos la vida más fácil. Su naturaleza ubicua y los avances en los dispositivos móviles han posibilitado el acceso a la Web en cualquier momento y desde cualquier sitio. Esto tiene numerosas y obvias ventajas, pero a su vez plantea retos en relación al Diseño Universal, debido a que los sitios web tienen que estar adaptados a diversos dispositivos y contextos de interacción. Para asegurar la accesibilidad de un sitio web, además de la diversidad humana, hay que tener en cuenta también las características de los dispositivos con acceso a Internet, incluso las del entorno donde ocurre la interacción. De forma similar, esa información se puede usar al evaluar la accesibilidad de los sitios web, de manera que las evaluaciones estén más cerca de lo que los usuarios experimentan al acceder a un sitio web.

En esta tesis se presenta una herramienta para evaluar la accesibilidad web a medida de los dispositivos móviles, y un sistema para la generación automática de interfaces web adaptadas al usuario. La herramienta de evaluación automática maneja información específica de dispositivos móviles. Los datos empíricos demuestran que se obtienen informes más precisos y fiables en comparación a realizar evaluaciones donde no se tiene en cuenta información específica de los dispositivos. El sistema generador de interfaces maneja información relativa a los usuarios y su contexto de interacción. Mediante el caso de estudio llevado a cabo, se concluyó que las interfaces generadas automáticamente adaptadas a los usuarios eran completamente operables. Éstas dos herramientas pueden ser de gran ayuda para los desarrolladores web para la creación y mantenimiento del contenido accesible teniendo en cuenta un amplio rango de usuarios y contextos de interacción.

Sin embargo, las interfaces accesibles y adaptadas no necesariamente proporcionan una experiencia de usuario mejorada. Con el objetivo de investigar como influyen las interfaces accesibles en la experiencia de los usuarios, y entender si la accesibilidad esta relacionada con una mejora en la experiencia de usuario, se realizó una prueba de usuario. Para investigar esta relación, se analizaron datos de los 11 participantes sobre sus percepciones de accesibilidad y su experiencia de usuario con cuatro sitios web con diferentes niveles de accesibilidad. Los resultados demuestran que la experiencia de usuario y la accesibilidad percibida de los participantes están estrechamente relacionadas. Además, la accesibilidad web está correlacionada con tres atributos (típica - original, conservadora - innovadora, aburrida - interesante) de la cualidad hedónica de la experiencia de usuario. Estos resultados aportan a la comunidad web conocimiento adicional sobre la interacción entre la experiencia de usuario y la accesibilidad web.

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Chapter 1

Introduction

This chapter makes an introduction to current challenges in web accessibility from the perspectives of evaluating the accessibility of websites, developing adapted user interfaces and understanding users' subjective experience on the Web. It also states the research questions addressed in the present PhD dissertation and the main contributions of this work.

The World Wide Web (as known as www or the Web) has changed the world and people's life incredibly since it was created. It has connected the world in an unprecedented way, as it provides people with an easier way to access and share information. There is a huge variety of websites and web applications, these allow us to carry a wide rage of tasks in our everyday life. Not only general purpose activities like searching for or sharing information, but also more specific ones related to particular domains, such as education, employment, banking, leisure, communication, commerce or health care. Due to the wide range of services offered through the Web, it has an incredible potential to facilitate our lives and the Web has become a very important resource in many aspects of our life. The Web can be particularly helpful for people with disabilities, since barriers to communication and interaction that many people face in the physical world are removed on the Web. Ensuring that websites are accessible is therefore essential in order to provide equal access and equal opportunities to people with disabilities.

The Web was designed to be universally accessible, which implies that it can be accessed by everyone, whatever their hardware, software, language, culture, location, or physical or mental ability[1]. Nevertheless, in practice this does not always happen, mainly because websites are often designed without considering human diversity. This leads to poorly designed web technologies (such as websites that contain accessibility barriers) which cause the exclusion of people with disabilities from using them. According to the World Health Organization (WHO)[2] over a billion people (about 15% of the world's population) have some form of disability. Furthermore, the rates of disability are increasing, in part due to ageing populations and an increase in chronic health conditions. In fact, millions of people around the world have disabilities (including visual, auditory, physical, speech, cognitive, and neurological disabilities) that have an impact on how they access to the Web.

In order to palliate this situation the World Wide Web Consortium (W3C) launched the Web Accessibility Initiative (WAI) in 1997[3], which has been working to promote the accessible web design since then. According to the WAI [53], web accessibility means that people with disabilities can use the Web in a comprehensive way, that is, they can perceive, understand, navigate, and interact with and contribute to the Web. This directly relates to the four principles (P, O, U, R) that relate to web accessibility; that is, web content must be perceivable, operable, understandable and robust. One of

[1] http://www.w3.org/standards/webdesign/accessibility

[2] `http://www.who.int/mediacentre/factsheets/fs352/en/`

[3] `http://www.w3.org/Press/IPO-announce`

the main roles of the WAI to promote accessibility is the creation of international standards that describe guidelines for the different components involved in the accessible web development. One of the most widely known guideline set is known as Web Content Accessibility Guidelines (WCAG) [29], [24].

There are interdependent components of web development that have to work together in order to make accessibility possible (see Figure[4] 1.1). Web developers, using adequate development and evaluation tools, should create web content that works correctly with the browser and assistive technology (such as screen readers) employed by users. Beyond developers and users, tools such as assistive technology, browsers, authoring tools and evaluation tools also play an important role.

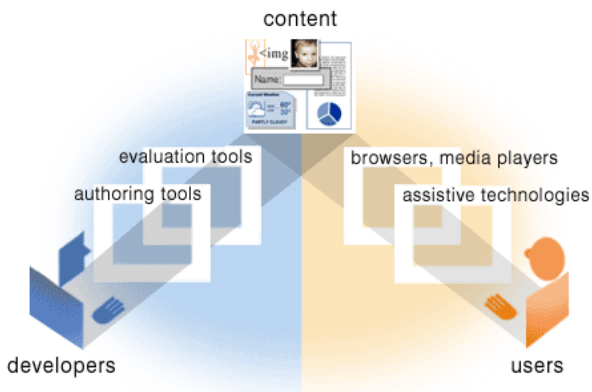

Figure 1.1: Components of web accessibility [52].

Those interdependencies among designers/developers, users and tools, make web accessibility more than an intrinsic property of websites though. It is a complex quality and there is no agreement on its definition yet [124].

Web accessibility does not exclusively benefit people with disabilities though. Research has shown that users without disabilities accessing the mobile web can experience similar difficulties to users with disabilities on the Web [123], [47], [122]. Mobile users can be considered as having situationally-induced impairments and disabilities (SIIDs) [102], which include the case of any user facing limitations derived from the environment. Some other examples of SSIDs include users of text-based browsers, with reduced internet speeds, or using devices with a small screen, interacting with touch screen devices on the move, in poor lighting conditions, or in noisy environments.

[4] https://www.w3.org/WAI/intro/components.php

Being aware that the access device affects the interaction of users on the Web, the W3C through the Best Practices Working Group (BPWG) as part of the Mobile Web Initiative, released the Mobile Web Best Practices (MWBP) [85]. These best practices were intended to provide guidance for the development of mobile websites, and improve the user experience on the Web when accessed from mobile devices.

With the objective of accurately deploying mobile web guidelines into evaluation tools, two test sets were released: mobileOK Basic Tests 1.0 [85] and mobileOK Pro Tests 1.0 [99] being the latter supposedly more demanding than the former. Therefore, mobileOK tests were regarded as the techniques in order to precisely implement Mobile Web Best Practices at a different demand level.

In addition to the best practices, the W3C released an online tool (the mobileOK Checker[5]) to evaluate the level of mobile-friendliness of websites based on the mobileOK Basic Tests 1.0. Nevertheless, since mobile devices had so different technical profiles, the results of the evaluations of websites (according to those mobile tests) were based on a generalisation of a common profile (so called Default Delivery Context, DDC). As a consequence, results of the tool offered an approximation of the level of mobile friendliness of the evaluated website. However, users accessing a website from mobile devices with different features would experience the interaction quite differently. In order to reduce this ambiguity and produce more reliable evaluation results, which were closer to the reality of mobile heterogeneity, it would be interesting to develop a tool that would evaluate websites taking into consideration the technical features of access devices. Chapter 3 presents an online evaluation tool of mobileOk tests, which takes into consideration the particularities (software and hardware) of different access devices. A conducted statistical analysis shows that there is a significant difference between the evaluation performed through this tool in comparison to a generic evaluation approach.

Based on the accessibility definition that includes barriers derived from the interaction context [122], the presented tool contributes to the improvement of accessibility from the evaluation point of view. Nevertheless, even though these best practices and tests were a first step towards developing mobile websites that enhanced the user experience, and relationships between WCAG and MWBP have been identified [30], [27], [32], these mobileOk tests were not based on specific requirements of disabled mobile web users. Consequently, more research was required in order to investigate how to improve the accessibility of the mobile web for users with

[5] `http://validator.w3.org/mobile/`

disabilities.

With the growing usage of mobile devices to connect to the Internet and access the Web (see Figures[6] 1.2 and 1.3), accessibility awareness and implementation is critical. Specially considering that the ubiquity of web browsers that can be currently found not only in computers and mobile phones but in a myriad of devices, such as ATMs, car navigation systems or even in home appliances. This ubiquitous web access allows users to access web-based services on the move, from any location through a wide range of devices.

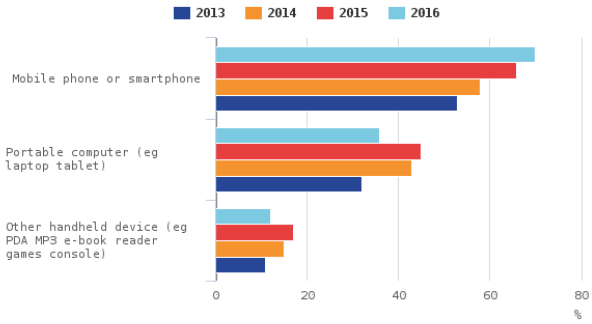

Figure 1.2: Internet use "on the go" (away from home or work) by device, 2013 to 2016, Great Britain (Source: Office for National Statistics).

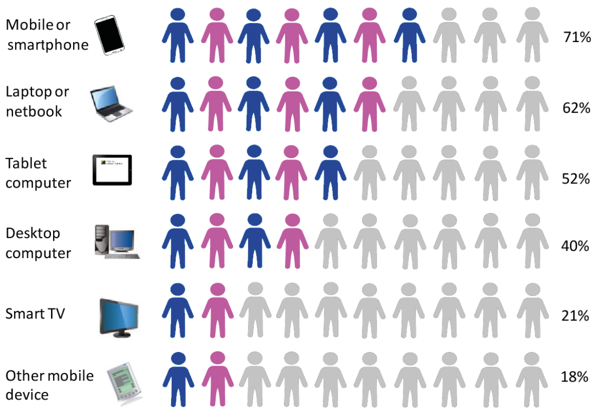

Figure 1.3: Devices used to access the internet, 2016, Great Britain (Source: Office for National Statistics).

This diversity of contexts and environments where the Web can be accessed

[6] https://www.ons.gov.uk/peoplepopulationandcommunity/householdcharacteristics/homeinternetandsocialmediausage/bulletins/internetaccesshouseholdsandindividuals/2016

from, offers unlimited opportunities for end-users. It can be especially helpful for people with disabilities, as they can access the resources and services offered through the Internet from their own smartphones, which are usually already adapted to their needs and preferences.

Nevertheless, even if their access device is already adapted to their needs, the web content has to be accessible. In this context of ubiquitous web access, where not only websites but other web resources can be pervasively accessed, it is unlikely that a single user interface design would satisfy the needs of all potential users (using different access devices in diverse environments). This scenario of ubiquitous web access implies big challenges with regard to the design and development of accessible web-based user interfaces. This can be addressed by providing adapted UIs that would suit each user's needs. However, manually designing and creating UIs for each possible situation is not feasible in this context. The characteristics of the ubiquitous environments allow knowing the features of users' interaction context and this allows following a model-based approach for automatically generating UIs adapted to the needs of users. Chapter 4 describes a user interface generator system designed for ubiquitous environments. Its main objective is to automatically generate adapted user interfaces for people with disabilities. These user interfaces are adapted to the abilities of users based on the information stored in models. In this way, users can operate web-based services (which are supported by ubiquitous computing), such as information kiosks or vending machines through adapted user interfaces on their own device. The outcomes of a user testing show that the automatically generated adapted user interfaces were fully operable.

Accessible and adapted UIs should provide users not only with access to web resources, but with an enhanced user experience. It may be worthless to provide users with accessible and adapted UIs if that does not have a positive impact on their user experience. This asks for a deeper understanding of the relationship between the web accessibility and the subjective experience of users. Chapter 5 describes the results of a study which was conducted with the aim of gaining a more comprehensive knowledge on the relationship between these two qualities. Results indicate that even if the user experience is closely related to the experienced accessibility (how users perceived the accessibility of websites); when it comes to web accessibility (measured by means of different evaluation methods and tools) how this is related to the user experience is not that clear.

1.1 Research questions

Three key research questions have been considered in this thesis with regard to web accessibility from the perspectives of evaluation, user interface development and user experience. The first one focuses on the accessibility evaluation. Specifically on how automated evaluations can be adapted to accommodate context information, such as access device characteristics. The second question is centred on creating web-based adapted user interfaces for people with disabilities. In particular, this question explores how to automatically generate accessible and adapted user interfaces based on the information from the interaction context of users with disabilities. The third question aims at investigating how the accessibility quality is related to the user experience. The main goal is to understand whether accessible user interfaces lead to a better user experience.

1. Is it possible to evaluate web accessibility considering context information? Can we build an automated framework which is able to evaluate the content of web pages considering access device features?

   Taking into consideration context information is of utmost importance with regard to make web accessibility evaluations less generic and more accurate. This is particularly necessary considering the wide range of devices that exist today which enable access to the Web, and the fact that the access device heavily affects the interaction context of users. To answer this question mobile web guidelines will be employed. Those best practices will be studied in order to identify the dependencies on device features. Those dependencies will be modelled by means of a semantic web notation. Best practices will be extended in order to consider those device dependencies. By incorporating those extended guidelines into a tool, websites could be evaluated according to different mobile phone models. This will result in device-tailored evaluation reports which will be more accurate than those results obtained from evaluations where context information is not taken into account. This question will be addressed in chapter 3.

2. Is it possible to automatically generate adapted UIs of various services and for different users? Can we build an automated system which is able to generate multiple versions of UIs based on the requirements of users?

   In order to address this question and build a UI generator, user modelling techniques and user interface description languages will be studied. In addition, the most adequate modalities and adaptations will be identified to consider the diversity of user capabilities. Such a system is desirable, as it could enable users with disabilities use services provided in ubiquitous environments in an accessible way. Beyond the benefits from an end-user point of view, such a tool can be of great help for designers and developers in the context of ubiquitous services, where multiple versions of user interfaces have to be created to cater the needs of all potential users. Chapter 4 will deal with this question.

3. Do accessible websites provide users with a good user experience? How do users experience web accessibility? How are web accessibility and user experience related?

   So far, there is no previous work on the subjective experience of users about the web accessibility of websites. As the success of a website often goes beyond its objective properties (e.g. content, functionality), it is a key issue to investigate the experience of users. The understanding of the interplay between the UX and web accessibility is key to design websites and web-based user interfaces that are not only accessible, but also provide an enhanced experience. Chapter 5 will be focused on this question.

1.2 Contributions and publications

This thesis has three significant contributions to the field of web accessibility.

Firstly, an automated device-tailored evaluation tool has been developed. More specifically, it has been shown how the information of mobile devices can be used as part of the context information for the automated accessibility evaluation. Outcomes of the case study show that more precise evaluation results have been obtained through the use of the developed evaluation tool. The followed methodology for the incorporation of device information in the automated process of assessing web accessibility is flexible and applicable for a wide range of devices, and even sets of guidelines that may be released in a future. This work was published in two peer-reviewed papers ([117] and [118]).

Secondly, a system that automatically generates adapted interfaces that allow users with different needs to access ubiquitous services from their own device has been presented. Although the topic of adapting interfaces has been explored before, this system has as a novelty the automation of the generation process of the adapted interfaces. Adapted user interfaces are focused on users with different needs who want to access services from their own devices (with different characteristics). This system is sufficiently flexible to generate various versions of the same interface corresponding to a particular ubiquitous service, taking into account user context information. The outcomes of this research have been published in [2], [81], [10] and [38].

Finally, this thesis examines the interaction between web accessibility and user experience. This work offers a new approach to examine the relationship between web accessibility and user experience. Not only because of the number of dimensions analysed but because different perspectives of web accessibility have been taken into account. This work led to the publication of two technical reports (see Appendix A) and four peer-reviewed papers ([7], [6], [8], [11]).

Chapter 2

Background and related work

This chapter presents the background and related work of previous research in the field of web accessibility. The chapter is divided into three main sections corresponding to these three areas of web accessibility covered in this thesis. In the first part, an overview of web accessibility evaluation methods available in the literature is provided, with a specific focus on automated evaluation. In the second part, a review of the approaches for the automatic adaptation and generation of accessible web-based user interfaces is presented. Finally, User Experience (UX) as a sub-discipline of HCI is introduced, and an overview of the area is provided.

2.1 The Web

The World Wide Web (WWW), known as the Web, is constantly evolving through the creation and adoption of new web standards and technologies. The Web as we know it today is a universe of applications and interconnected websites, full of information in form of text, images, videos and interactive content. The evolution of technology has allowed developers to create new web experiences. The scope of web development can range from creating a simple static plain text Web page, through creating websites with dynamic content, to developing more complex web applications, usually known as Rich Internet Applications (RIA). Therefore, websites and Web applications have a wide range of degrees of complexity and they can be classified depending on their development history and their degree of complexity, ranging from document-centric static websites to ubiquitous Web applications providing location-aware services [59]. Due to the heterogeneous nature of web-based applications, web engineering encompasses inputs from diverse areas [83]:

- Requirements specification and analysis
- Web-based systems development methodologies and techniques
- Migration of legacy systems to Web environments
- Web-based real-time applications development
- Testing, verification and validation
- Quality assessment, control and assurance
- Configuration and project management
- "Web metrics" - generating metrics for estimation of development efforts
- Performance specification and evaluation
- Update and maintenance
- Development models, teams, staffing
- Integration with legacy systems
- Human and cultural aspects
- User-centric development, user modelling and user involvement and feedback
- End-user application development

- Education and training

When it comes to the development of websites, it generally requires knowledge on Web technologies (client-side and server-side programming), Information Architecture (IA), Search Engine Optimisation (SEO) and User Interface (UI) design among others.

One of the most challenging aspect is related to the user interface design and development of Web applications. Since the UI design discipline belongs to the Human-Computer Interaction (HCI) field, it involves mastering aspects that range from disciplines such as computer science and software engineering, to psychology and cognitive science. Therefore, the design of a proper user interface is not a trivial issue. Specially when the needs and abilities of potential end-users are not known in advance. In this regard, the concept of *Universal Access* aims to guarantee that websites are developed to work for the largest possible audience using the broadest range of hardware and software platforms [109]. The World Wide Web Consortium (W3C) has been supporting different initiatives in order to promote the *Universal Access* paradigm.

2.2 Web accessibility

Web accessibility is a fundamental requirement for ensuring a universal access to the Web [109]. Accessibility aims at achieving an inclusive Web, which means that people with disabilities are not discriminated against in any way with regard to the use of the services provided on the Web.

Web accessibility research is concerned with different perspectives related to the accessibility components mentioned in the previous chapter (see Figure 1.1). Efforts on web accessibility have been directed towards the definition of guidelines; the creation of evaluation methods and assessment metrics; the design and development of authoring and evaluation tools as well as assistive technologies; and the study of the needs and behaviour of users when they navigate the Web. In summary, research on web accessibility ranges from web content evaluation, the design and development of tools (for supporting both, web developers when creating accessible content, and users for navigating the web), to the understanding of the behaviour and requirements of users on the Web.

Nevertheless, there are still some disagreements in the community with regard to what accessibility means and entails, the adequacy of accessibility guidelines, its evaluation and measurement, and its impact on the user experience.

Definition

In spite of all the work that has been made in favour of web accessibility, there are different views on its meaning and there is no agreement on its definition yet. A survey [124] conducted with the aim to discuss different views and perspectives of accessibility, points out the difficulties to quantify, define and reach an agreement with regard to web accessibility.

One of the most widely known definition of web accessibility is the one from the W3C WAI[1]: *web accessibility means that people with disabilities can use the Web. More specifically, web accessibility means that people with disabilities can perceive, understand, navigate, and interact with the Web, and that they can contribute to the Web.* According to the Section 508 US regulation[2], technology is accessible if it can be used as effectively by people with disabilities as by those without.

There are other definitions of accessibility [17], [124] though, some refer in general to the universal access, others only refer to people with disabilities and others mention specifically properties such as effectiveness, safety and security.

Accessibility Guidelines

With the objective to support and promote accessibility implementation in web development, several guidelines have been released by different organisations. The most popular guideline set is the Web Content Accessibility Guidelines (WCAG) from the W3C. However, these guidelines are not the only ones. Other organisations and companies, such as the US Government (Section 508 Standard [1]), IBM (Web Accessibility Checklist[3]), Microsoft (Accessibility Design Guidelines for the Web [4]) or the BBC ([5]) have developed their own, inspired in many cases by the W3C guidelines.

Web Content Accessibility Guidelines (WCAG 1.0 [29] and 2.0 [24]), represent the best practices that web developers should follow in order to create accessible websites.

[1] `https://www.w3.org/WAI/intro/accessibility.php`
[2] `https://www.section508.gov/content/accessibility`
[3] `http://www-03.ibm.com/able/guidelines/web/accessweb.html`
[4] `https://msdn.microsoft.com/en-us/library/aa291312(v=vs.71).aspx`
[5] `http://www.bbc.co.uk/guidelines/futuremedia/accessibility/html/`

The WCAG 2.0 are organised around four principles: *perceivable* (P), *operable* (O), *understandable* (U) and *robust* (R)[6]:

- Perceivable - Information and user interface components must be presentable to users in ways they can perceive.
- Operable - User interface components and navigation must be operable.
- Understandable - Information and the operation of user interface must be understandable.
- Robust - Content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies.

Under each principle there is a list of guidelines to address it. There are twelve guidelines and each one includes a number of success criteria that describe what must be achieved in order to meet the guideline. The success criteria are written as testable statements for determining if web content satisfies them. There are three levels of success criteria (A, AA, AAA) and testing them can involve a combination of both, automated and human evaluation. For each success criterion there are specific sufficient and advisory techniques.

The W3C guidelines are considered as international standards for web accessibility and they have become an ISO standard (40500:2012) [56]. In many countries, web accessibility legislation employs the W3C guidelines as a reference framework. However, even if the guidelines help to avoid and detect possible barriers, their use does not completely guarantee that a website is fully accessible.

In fact, these guidelines have not been without criticism. Some have claimed that the specification of WCAG guidelines is lengthy and tedious to deal with, and that guidelines are complex to understand [31]. Other authors [19] pointed out the lack of scientific evidence of WCAG questioning their validity and reliability of these guidelines that claimed to be based on testable criteria. Other weaknesses of WCAG guidelines usually refer to their lack of coverage for some user groups (e.g. people with cognitive disabilities [104], learning and literacy difficulties). In order to tackle this issue, other guideline sets, that are targeted to specific user groups or focus on the interaction context, have been released. There are guidelines that aim at covering the needs of specific groups of users (e.g. WDGOP [66] for elderly

[6] https://www.w3.org/TR/UNDERSTANDING-WCAG20/intro.html

users, users with cognitive disabilities [84]), while others are focused on the characteristics of the access devices (e.g. MWBP 1.0 [93]).

The W3C itself has recently admit the shortfalls of the WCAG guidelines claiming that technology has evolved in an unforeseen way since the development of WCAG 2.0. To address these needs, the Web Content Accessibility Guidelines Working Group announced a plan to develop WCAG 2.1[7], which builds on but does not intend to replace WCAG 2.0.

Web accessibility evaluation

The release of the WCAG guidelines has led to the implementation of worldwide policies[8], and regulations (BITV German government standard [107], Stanca Act Italian government standard [43], RGAA French government standard [108], the BS 8878:2010 British standard [22]) or the European Standard EN 301 549 [28]. Each one with their own approach to accessibility and procedure to evaluate web resources for accessibility.

Evaluating web accessibility is essential in order to check that the adopted standards have been meet. Without the evaluation or the validation it cannot be determined whether a web resource is accessible or not. Web accessibility evaluation encompasses a wide range of disciplines and skills [4]. It can require knowledge not only about technical aspects related to web technologies, guidelines, standards and evaluation tools, but also non-technical aspects such as the involvement of end-users in the evaluation process.

The accessibility of websites can be evaluated by means of different methods [17]. Figure 2.1 shows a taxonomy of accessibility evaluation methods (AEMs) with a great level of detail, based for example on their purpose, type of results they produce, and the type of information they use as an input. With the focus on the evaluator, accessibility evaluation methods can also be grouped in three main groups: automated testing, manual inspection and user testing.

Automated testing is run by software tools or online services, which are also known as Accessibility Evaluation and Repair Tools (AERT). These tools (they will be further described in the next section 2.2) detect accessibility problems that can be automatically identified, supporting developers building and maintaining accessible websites.

Manual inspection is conducted by human evaluators [18]. Generally, it

[7] `https://www.w3.org/blog/2016/10/wcag-2-1-under-exploration/`

[8] Web Accessibility Policy Resources: `http://www.w3.org/WAI/policy-res`

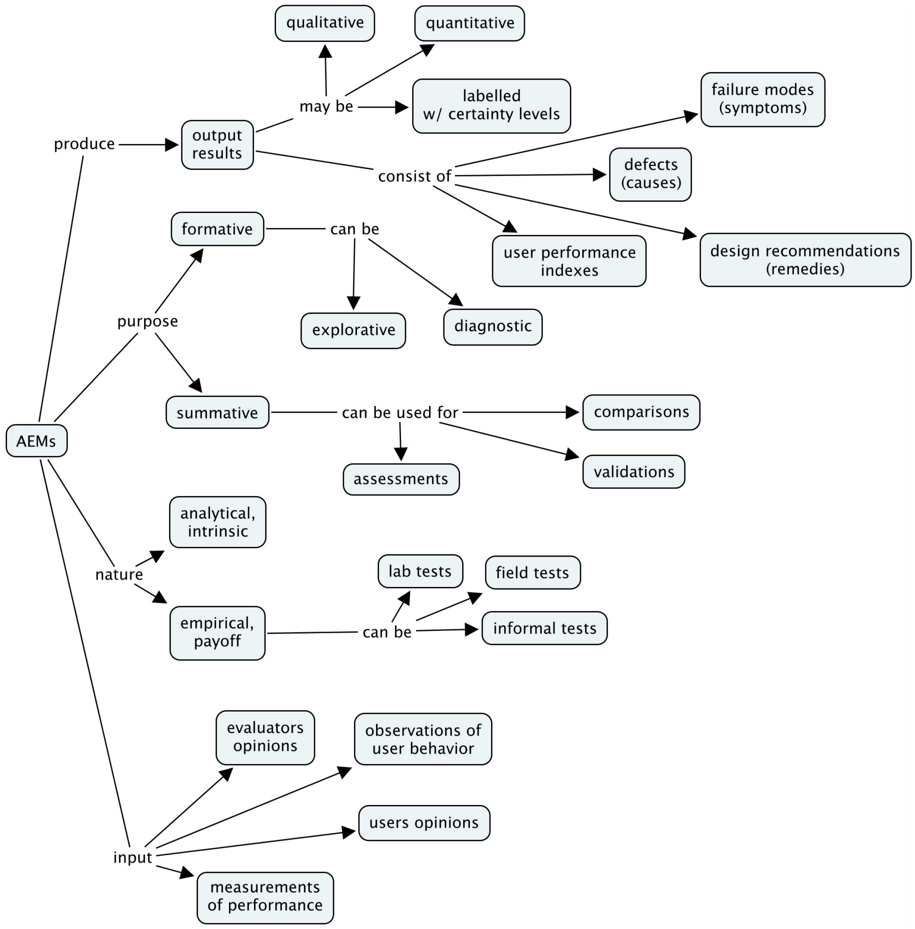

Figure 2.1: Taxonomy of accessibility evaluation methods [17].

entails checking if a page satisfies a list of accessibility criteria. The most widely used manual method is the conformance, expert or guidelines review, which consists of checking if a website meets a set of accessibility guidelines. The barrier walkthrough [41] is another example of a manual inspection method to evaluate web accessibility. It consists of identifying the severity and frequency of barriers on a website. A barrier, defined by the author of the method, is any condition that makes it difficult for people with disabilities to achieve a goal when using the website through specified assistive technology [18].

Involving users, for instance user testing for accessibility evaluation, is based on empirical usability tests where participants with disabilities are asked to perform a number of tasks individually. Depending on the design of the test, participants provide their feedback by different techniques (e.g. concurrent or retrospective think-aloud protocols, questionnaires or interviews), and the behaviour and interactions of participants are recorded and observed by evaluators, who can then synthesise their findings.

Even though a number of evaluation methods exist, it is not clear yet how they should be combined and organised in order to evaluate web accessibility [124]. The WAI's website contains a page with a list of accessibility evaluation resources[9] and points out different approaches for evaluating websites for accessibility. While it does not provide details on testing techniques, it contains information about general procedures and tips for accessibility evaluation in different situations, such as preliminary checks, Conformance Evaluation Methodology (WCAG-EM) [115], involving users in evaluation or selecting tools.

Automated evaluation tools

The automation of the accessibility evaluation process has been of particular interest on the accessibility evaluation research topic.

Even if automatic tools cannot replace human evaluation, in spite of their limitations they play an important role in accessibility evaluation. When used appropriately, they can provide developers and evaluators with support and significantly reduce the time and effort required to conduct an evaluation [4]. These tools are essential in order to help developers to analyse and monitor the accessibility quality of websites. Ivory and Hearst [57] highlighted some of the advantages of using automated tools:

- The evaluation process becomes less time-consuming, and consequently there is a reduction in costs.
- The errors detected are more consistent.
- It is possible to foresee the effort needed in the evaluation process, in terms of time and financial cost.
- The evaluation scope is broadened, as it is possible to analyse diverse aspects of the interface in a shorter period of time.
- It becomes easier for inexperienced evaluators to perform usability and accessibility evaluations.
- Comparison of the suitability of different user interface design alternatives is facilitated.

[9] `https://www.w3.org/WAI/eval/Overview`

- The incorporation of evaluation tasks during the development process is facilitated.

Although useful, these tools have also some weaknesses that are worth being aware of when using them. As a number of accessibility guidelines require human judgement to assess whether or not they are being met, automated evaluation tools are not able to deal with those guidelines. This usually results in false negatives (missed errors) or false positives (reported false issues).

When it comes specifically to accessibility checkers, there are numerous accessibility evaluation tools[10] and diverse criteria for classifying them:

1. Free vs. commercial: While a few of them are commercial tools, the majority of them are freely available.
2. Platform: they can be classified in local or standalone applications, online services or browser extensions, depending on where they run.
3. Evaluation scope: they can be classified in terms of what they examine, for instance, the number of pages inside a website.
4. Evaluation only vs. evaluation and repair: While most tools only provide the option to evaluate, some tools are also able to provide guidance on the repair process.
5. Reporting accessibility issues: usually tools report errors or failures, as a result of not passing an automated check (e.g. missing alternative text for an image); and warnings, as the outcome of a potential accessibility problem that needs a manual check (i.e. the suitability of the alternative text for an image).
6. Guidelines used: the standards or guideline sets they employ for evaluating accessibility.

Since the publication of the Web Content Accessibility Guidelines (WCAG 1.0 and 2.0 [29, 24]) a number of evaluation tools have been implemented. A complete list of available web accessibility evaluation tools can be found on the W3C-Web Accessibility Initiative (WAI) website[11]. Advanced search functionality is included on that website, which allows looking for evaluation tools according to some of those previously mentioned criteria: the type of tool, the provided assistance, the scope of evaluating single of groups of websites, the license type, and the used guidelines to evaluate.

[10] `http://www.w3.org/WAI/ER/tools/`

[11] A complete list: `http://www.w3.org/WAI/ER/tools/`

Examples of freely available automated accessibility evaluation tools found in the literature include AChecker[12] [40], EvalAccess[13] [3], [9] and Mauve[14] [100], [87]. Other tools have also a commercial version such as WAVE[15], TAW[16], or Tenon[17]. Most of the tools evaluate according to general purpose guidelines and regulations, such as WCAG, Section 508, Stanca Act or BITV. In contrast, beyond general purpose accessibility guidelines, TAW also includes the possibility of evaluating according to the device specific guidelines (mobileOk test [85]), and Mauve [100] offers the possibility to evaluate web content using end-user specific guidelines (usability criteria identified to improve web navigation for vision-impaired people).

2.3 Mobile web

The mobile web refers to the use of browser-based Internet services from handheld devices (such as smartphones, feature phones or tablets) through a mobile or other wireless network. As the Web started to evolve from the traditional access via fixed-line services on laptops and desktop computers to a more mobile access by portable and wireless devices, the community started to acknowledge the limitations of the mobile web. Although these access devices differed in their input and output modalities, in general they were quite limited. In fact, a number of them had reduced keyboards and small display size, which resulted in poor web experiences. In fact, low input rate, lack of a pointing device and low bandwidth were identified as the key factors that caused a decline in the quality of interaction [58].

The work that had been undertaken in the web accessibility field until then though was not only for users with disabilities. Mobile users started to be considered as having situationally-induced impairments and disabilities (SIIDs) [102], which include the case of any user facing limitations derived from the environment. Some other examples of SSIDs include users of text-based browsers, with reduced internet speeds, or using devices with a small screen, interacting with touch screen devices on the move, in poor lighting conditions, or in noisy environments. Some researchers therefore, started to find parallelisms between web accessibility and mobile web access. Research has shown that people without disabilities like mobile users

[12] `http://achecker.ca/checker/index.php`
[13] `http://sipt07.si.ehu.es/evalaccess2/`
[14] `http://hiis.isti.cnr.it:8080/MauveWeb/`
[15] `http://wave.webaim.org/`
[16] `http://www.tawdis.net/ingles.html?lang=en`
[17] `https://tenon.io/`

can experience similar problems to those with disabilities [123], [47], [122].

With the aim of raising awareness and providing guidance in the community, the W3C through the Mobile Web Initiative published the Mobile Web Best Practices 1.0 (MWBP 1.0) [93]. The W3C Mobile Web Initiative also introduced machine testable test sets based on MWBP 1.0: W3C mobileOK Basic Tests 1.0 [85] and mobileOK Pro Tests [99]. These best practices should be followed so that websites to be deployed in mobile devices could provide users with a satisfying interactive experience.

In this context, some evaluation and review tools were developed to validate the mobile friendliness of the content of web pages in relation to the best practices. EvalAccess mobile[18] [12] was one of the first tools for evaluating web content based on those best practices. The W3C mobileOK Checker[19] was an online and free service provided by the W3C that checked the level of mobile-friendliness of websites based on the mobileOK Basic Tests 1.0. Another online evaluation tool that used those test was the Mobile-OK Evaluator (mokE) [39]. The TAW mobileOk beta[20] from Fundación CTIC, also analyses the web content according to the W3C mobileOK Basic Tests 1.0. ReadyMobi[21] from Afilias Technologies Ltd (dotMobi) evaluates the web content based on W3C standards, Yahoo's YSlow[22], as well as Google's PageSpeed rules[23]. Three device models (known as "high tier", "mid tier" and "low tier") are emulated to measure how the evaluated web page performs across devices with different capabilities. Nevertheless, the issue with these tools is that even if they use specific guidelines for the mobile web, they do not take into consideration any context information. In fact, the tools that use the W3C mobileOK Basic Tests 1.0 [85], rely on the Default Delivery Context (hereafter referred to as DDC). The best practices document described the DDC as: "the minimum delivery context specification necessary for a reasonable experience of the Web". Thus, the DDC represented the minimum common denominator device profile (see Figure 3.1). Testing against DDC thus, does not represent a realistic scenario since the characteristics of the actual mobile devices differ from the values of the features defined in the DDC. The ReadyMobi tool goes beyond the DDC and takes into consideration three different mobile types that broadly represent the range of existing mobile devices. This last tool can produce more realistic evaluation results in comparison to the pre-

[18] http://sipt07.si.ehu.es/evalaccess2/mobile/index.html
[19] http://validator.w3.org/mobile/
[20] http://www.tawdis.net
[21] http://ready.mobi
[22] http://yslow.org/
[23] https://developers.google.com/speed/docs/insights/mobile

vious ones which only rely on the DDC. Nevertheless, a more fine grained approach could be undertaken when it comes to evaluations where the specific characteristics of different mobile devices are considered.

2.3.1 Device-tailored evaluation

As far as automatic evaluation is concerned, relying on the DDC reduced tool effectiveness, due to the fact that most access devices differed from the features defined in the DDC.

Usable screen width: 120pixels, minimum.
Mark up language support: XHTML Basic 1.1
Character encoding: UTF 8
Image format support: JPEG, GIF
Maximum total page weight: 20 KB
Colours: 256 minimum
Style sheet support: CSS Level 1
Scripting is not supported

Figure 2.2: Characteristics of the DDC.

In this regard, two different problems were identified when it comes to mobile web content automatic evaluation:

- False positives are those problems detected which are not actual issues. Devices with more advanced capabilities are able to handle numerous data formats, support scripting, etc. Therefore, a tool assuming that these devices cannot deal with such issues will produce false positives. For instance, these types of problems arise when the mobileOK Basic test "3.22 Tables Alternatives", which warns about the use of table elements in web pages, is applied. The DDC based evaluation would return a warning even if a device actually supports tables. Another example of false positives related to the mobileOK Basic tests is "3.8 Image maps", which if an image map is found an error will be returned by the DDC based evaluation, even if the device can deal with them.

- False negatives are those undetected but real issues. All devices were supposed to meet the DDC, including those that have fewer capabilities, thus, false negatives are produced. Even nowadays, in the era of the smartphones, there are still "dumb" phones available in the market, which are basic phones with low end features (i.e. Nokia 215 model). For instance, when "3.4 Content format support" mobileOK Basic test is applied, it will be assumed that a given device supports JPEG or GIF picture format. The DDC based evaluation would miss those issues produced by devices that actually do not support these formats.

Obviating these problems would cause a decrease on the effectiveness of the evaluation tools, which is defined in terms of completeness, correctness and specificity by Brajnik [15].

Chapter 3 presents an application that considers specific device features in the evaluation process to produce device-tailored reports. As a result, higher rates of evaluation tool completeness, correctness and specificity are obtained. Chapter 3 explains how mobile best practices were analysed in detail to identify the dependencies they had with regard to device features. Best practices were modified in order to accommodate those dependencies and coded into an evaluation tool. Using the Composite Capabilities/Preferences Profiles (CC/PP) [44] (a W3C-developed generic model based on RDF[24] for describing device capabilities and user preferences) device profiles were created from data on existing device repositories. Data in profiles was used to complete and enrich evaluation tests, and thus make more accurate evaluations.

2.4 User-tailored interfaces for people with disabilities

Models and profiles are not only useful for adapting the evaluations to the features of particular mobile devices, but for adapting the user interface to the specific needs of the users. In fact, user interface adaptation for users with disabilities has been acknowledged as an alternative way to achieve the universal access paradigm.

The success of the mobile web alongside with the advances in the ubiquitous computing field, have led to a ubiquitous web, which entails that web resources can be accessed by any user, through any device, from any location at any time. One of the most important characteristics of Ubiquitous Computing is context awareness. According to Dey, context-aware systems use context to provide relevant information and/or services to the user [34]. Context is considered as *any information that can be used to characterise the situation of an entity. An entity is a person, place, or object that is*

[24] `https://www.w3.org/TR/2004/REC-rdf-mt-20040210/`

considered relevant to the interaction between a user and an application, including the user and application themselves [34]. Ubiquitous web access focuses then on providing users with access to services and information from a web-based interface.

In this context, the design of a unique user interface can hardly cope with the features of a ubiquitous web access and satisfy the needs of all the potential users. Even if general purpose accessibility guidelines are applied, these guidelines usually follow a design for all approach, and compliance with them does not always ensure the accessibility for each user due to the diversity of interaction contexts.

A common approach to provide users with disabilities with an accessible user interface has been the adaptation of an already existing user interface into a more accessible one. Applications and services in the area of ubiquitous web though, are often facing the issue that at design time it is not known what devices will be accessing them at runtime and what preferences the user will have. Creating different versions of a user interface for each service or application could be a solution to avoid accessibility problems. Nevertheless, this approach is not always feasible due to the extra effort in creating and maintaining a number of user interfaces for a single application.

A model-based approach for the automatic user interface generation would be a useful solution in this context.

Modelling

Modelling techniques are generally employed to build up a representation of users, in order to customise and adapt systems to their specific needs [62], [63]. The model is a key component of an adaptive system as it maintains the user's properties, such as preferences, interests, behaviours, knowledge, goals and other events that are relevant to user adaptation [26]. People with disabilities can greatly benefit from user-modelling techniques.

Preliminary attempts to merge the knowledge and techniques between user modelling and universal access field were carried out in the AVANTI project [36]. The aim of the AVANTI project was to cater hypermedia information to users with special needs by adapting the content and the presentation of web pages to each individual user. A model of the characteristics of users including interests and preferences, domain knowledge and computers usage expertise was employed in the adaptation process. The Composite Capabilities/Personal Profiles (CC/PP) [44] (as mentioned in section

2.3.1) has also been used for modelling hardware, software and user agent characteristics. The vocabulary of CC/PP for describing user profiles is limited, though. In order to enhance the expressiveness of CC/PP descriptions, new vocabularies can be defined. Velasco et al. [114] present a user profile based on CC/PP. The components of the user profile include personal information, user preferences with regard to input–output modes, interaction preferences regarding navigation and search mechanisms and delivery context information, such as location and time. Vigo et al. [116] introduced the personal accessibility profile, which is implemented based on CC/PP and includes information on users' assistive technologies as a foundation for achieving personal web accessibility. Nevertheless, these CC/PP based modelling examples are do not cover all context information required for the automatic user interface generation of adapted user interfaces in ubiquitous environments. There are more examples of how user modelling techniques can be applied to improve web accessibility [95], however, these approaches include limited context information while they focus on user and device models.

A model can include a wide range of information from the interaction context of users, represented in diverse ways. For instance, Schmidt et al. [101] propose a hierarchical model in which two different contexts are distinguished on the top level: 1) human factors, including user, social environment and task; and 2) physical environment, gathering conditions, infrastructure and location. Göker and Myrhaug [42] structure the context by modelling the following concepts: personal, environmental, task, social and spatio-temporal. Krüger et al. [64] use the following categories: physical, spatial, temporal, activity and situation. Brusilovsky and Millán provide a wide review of user modelling approaches applied to the adaptive web [21]. Beyond features such as users' knowledge, interests, goals, background or affective state, they also discuss modelling the context on users including concepts such as the type of platform used or the location from where they interact. Gu et al. presented a context model based on an ontology written in the OWL language [45]. This model represents context by defining an upper common ontology for general background information and a series of low-level ontologies, which can be applied in different sub-domains. The class ContextEntity for declaring the upper ontology presents a set of descendant classes of Person, Location, Computational Entity and Activity.

These approaches to model the context are not specifically for users with disabilities though. In fact, there are not so many models for ubiquitous environments which consider users with disabilities. One example is the

Inredis[25] (INterfaces for RElations between Environment and people with DISabilities) project, which aimed to provide universal accessibility, interoperability and ubiquity in order to allow people with disabilities to control applications and devices such as service machines, vending machines or home appliances, via multiple devices (smartphones, tablets, etc.). The model designed within the project consisted of a global ontology including other 6 ontologies: user, access device, target service, user interface, adaptation and assistive technology ontologies [82].

The diversity in the modelling for adaptation and personalisation is largely due to the dependence on the application domain, as there is a wide range of applications and services with different requirements on which this technique can be applied into. The variety is not only with regard to the concepts that are modelled but to the implementation of the model itself. In this regard, models can be implemented by means of different technologies. For instance, as a collection of keywords [86], by means of XML or database schemas [50] or employing semantic web technologies (such as RDF[26] and OWL[27]) [51] to name a few.

Considering the complexity of context-sensitive applications or services that can be ubiquitously accessed, ontology-oriented modelling might be the best approach because it provides a high level of expressiveness and formality, based on semantic web technologies. These models can potentially share knowledge and are capable of reasoning using context information. This type of context modelling seems promising for advancing in the development of ubiquitous systems. This applies not just to offering services ubiquitously within the same architecture, but also to going further and ensuring access to ubiquitous services belonging to different environments and different ubiquitous architectures.

2.4.1 Creating adapted user interfaces

Modelling techniques are the basis for user interface adaptation, which has an incredible potential for people with disabilities with regard to improving and personalising the access to web-based services and resources.

[25] `www.inredis.es/`

[26] `https://www.w3.org/TR/2014/REC-rdf-schema-20140225/`

[27] `https://www.w3.org/TR/owl-features/`

Adaptation methods

There is a wide range of methods and techniques for adapting and personalising user interfaces. Knutov et al. [61] classify adaptation methods into three main categories, depending on the part of the user interface it applies to: content, presentation and navigation. Nevertheless, some methods can belong to more than one category since the adaptation can be applied simultaneously to content and presentation, or to navigation and presentation (see Figure 2.3).

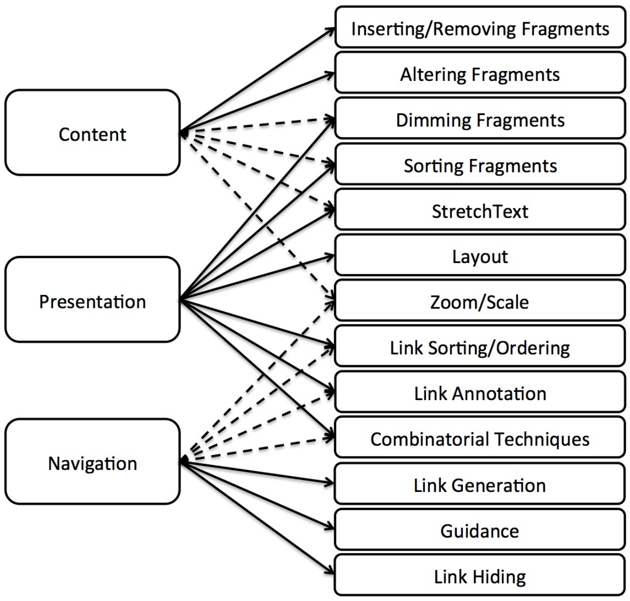

Figure 2.3: Classification of adaptation methods [61].

Content adaptation methods refer to those which modify the parts of content of the user interface. Some examples include adding, deleting or modifying the content, whereas others just emphasise the content as a suggestion of the most relevant content according to the interests or needs of the user. These methods are usually oriented towards providing users with personalised content.

Navigation adaptation methods are divided into two main categories: suggesting and enforcing techniques. Suggesting techniques emphasise or order the links of a website. By contrast, enforcing techniques remove non-relevant links or add new ones.

Presentation adaptation methods modify the style and layout of the user interface. Previously mentioned content adaptation methods that emphasise parts of the content of websites can also belong to this category. Similarly, navigation methods that modify the style of user interfaces, can also be included in the presentation category (e.g. using coloured links).

Automated generation of adapted web-based user interfaces

The massive expansion of the Internet has promoted the application of adaptive interaction methods for improving the access to the Web. As mentioned before, these methods focus on adapting the navigation, content and presentation schemes [21]. What is not so common in this field is to find systems where the adaptations are aimed at improving the accessibility for people with disabilities. As previously mentioned, first steps towards the combination of the user modelling and universal access fields were made through the AVANTI project [36], which aimed to provide users with special needs with hypermedia information by adapting the content, navigation and presentation. Transcoding techniques [13] had been also used to transform inaccessible web content into accessible content on the fly. For example, the SADIe transcoder [77], which adapts news websites for blind users. This approach differs from the work presented in this thesis (see chapter 4) in that it is focused on websites and only considers visually impaired users.

In recent years, personal computing has evolved from the use of laptops to ubiquitous interactions with handheld devices. In the web environment, Responsive web design (RWD)[28] has been a useful solution to shift design focus beyond the ordinary desktop experience to ensure availability of websites across a multitude of devices. While it was not created specifically to address accessibility, RWD enables the website to adapt its layout to the format of the viewing environment through the use of proportion-based grids and CSS3 media queries. Nevertheless, this approach is only focused on the screen size of the access devices and does not consider the needs of the users.

Ubiquitous services are usually provided by means of generic interfaces that may contain barriers for people with disabilities. To overcome this problem, the use of adaptable or adaptive user interfaces is recommended. Adaptable interfaces allow the user to tune certain parameters of the display. Adaptive interfaces are able to automatically adapt themselves to the user's characteristics [36]. For instance, this latter approach was adopted by Savidis and Stephanidis [98], who describe ways to automatically adapt interfaces to users by considering their requirements, capabilities and preferences, as well as the interaction context.

[28] `https://responsivedesign.is/`

Nevertheless, the requirements of the adaptive web differ significantly from those needed for adapting the access to ubiquitous services. In the former case, the main goal is to adapt an existing website; whereas in the latter case the objective is to generate an adapted user interface to use a local service. Although both types of interfaces can be coded using the same technology (e.g. web technology), their aims, structure and organisation are different.

In the process of automatically generating user interfaces from different sources, the use of User Interface Description Language (UIDL) [46] can be useful. UIDLs allow designers and developers to specify a user interface, using high-level constructs that abstract away implementation details [105]. These languages allow the construction of abstract user interfaces, which can describe the main functions of a service, being independent of the modality and the platform in which they will be rendered. The principal goals of UIDLs are [78]:

- To capture the requirements of a user interface as an abstract definition that remains stable across a variety of platforms.
- To enable the creation of a single user interface design for multiple devices and platforms.
- To improve the reusability of a user interface.
- To support evolution, extensibility and adaptability of a user interface.
- To enable automated generation of user interface code.

Limbourg et al. [74] proposed the User Interface eXtended Markup Language (UsiXML). It is an XML-compliant markup language that describes the user interface for multiple contexts of use. It includes various models at different abstraction levels, such as a task model, an abstract UI model, a concrete UI model, and a transformation model. Paternò et al. [88] present the Model-based lAnguage foR Interactive Applications (MARIA), a model-based UI description language for providing support to service-oriented applications, both at design time and at run time. At run time, MARIA supports automatic generation of UIs tailored to different devices. The User Interface Markup Language (UIML) [91] provides a mechanism to map different types of resources to each specific interaction element. UIML has been adopted for the development of the UI generator system presented in this Thesis (see chapter 4) due to its flexibility with regard to specifying user interface resources.

Different UI generators can be found in the literature but only a few of them provide users with disabilities with accessible user interfaces [82], [35]. The previously mentioned Inredis[29] (INterfaces for RElations between Environment and people with DISabilities) project [82] where a user interface generator system was created. The generated web-based user interfaces were based on certain user stereotypes and three different UI types: textual user interface, an iconic interface and a combined interface which incorporates both textual and iconic elements.

GUIDE [35] is another example of an adaptive system for users with special needs. It is a multimodal adaptive system which provides elderly users with adapted UIs for interactive TVs.

The aim of the work presented in this Thesis (see chapter 4) was to go beyond the home environment and provide UIs beyond specific stereotypes.

2.5 Understanding the experience of users

Web-based user interfaces and websites in particular are much more than interactive artefacts which users interact with just for accomplishing specific tasks. Individuals find the Web a mean, not only for working or achieving informational goals, but also for different purposes related to communication, leisure, social networking or contributing to building the Web, to name a few [75].

Users value interactive artefacts on the basis of how well they satisfy their needs in a particular situation [48], beyond the objective features of the websites (e.g. content, style, functionality that derive from design choices). Therefore, the success of a website depends not only on its characteristics, but on how well these are perceived by end-users [48]. This highlights the importance of considering the subjective aspects of the interaction beyond exploring task related aspects of the interaction, in order to understand the actual experience of users.

The User Experience

In this regard, the Human Computer Interaction (HCI) community has acknowledged the importance of non-instrumental aspects beyond the task related aspects. According to the ISO 9241-210:2010 user experience is defined as "a person's perceptions and responses that result from the use and/or anticipated use of a product, system or service" [55]. The abstract and subjective nature of the term makes it hard to reach an agreement on

[29] www.inredis.es/

its definition. As an attempt to frame the concept of user experience, Law et al. [70] conducted a survey to gather the views of researchers and practitioners from academia and industry. Results of the survey show that the UX concept is considered as dynamic, context-dependent and subjective. As a relatively new research area, UX has been addressed in different ways in the HCI literature.

An analysis of a sample of the empirical studies published from 2005-2009, reported how differently research on UX was conducted in terms of the studied artefacts, the analysed UX dimensions and the applied methodologies [14]. The analysis showed that different types of interactive artefacts were used in UX research but with a predominance of those related to art and mobile app/phone. In fact, only 12% of empirical user experience studies employed websites as stimuli. With regard to the assessed UX dimensions, the most frequent dimension was *Generic UX*, which was used for the cases derived from qualitative studies where the analysed UX dimensions were not reported. When it comes to the nature of the studies, half of them were qualitative, and only 17% used both, quantitative and qualitative methodological approaches.

Regarding data collection methods employed in UX research, self-developed questionnaires were the dominant method. Even though the study showed that there has been a shift towards qualitative approaches from more traditional quantitative ones, it also uncovered the heterogeneity and the lack of agreement related to UX research, about its definition, UX dimensions and research techniques to evaluate it.

Due to its abstract and intangible nature, UX dimensions, aspects, properties and attributes to measure it are still unclear. In fact the measurability of UX is still an unresolved issue [71] and it can be tackled from different approaches. Those in the holistic camp support qualitative approaches and they question the utility of measuring UX attributes. They argue that numeric values may not be enough to help us understanding the complex interactions between humans and machines. In contrast, the reductionists rely on quantitative approaches based on models to understand, represent and evaluate UX. Law [69] claims that each approach has specific strengths and weaknesses, and she states that hybrid approaches, which combine both qualitative and quantitative methods, are often recommended for obtaining more valid empirical findings. The work presented in this thesis combined both, qualitative and quantitative approaches based on existing UX models in order to have a solid foundation (see Chapter 5).

There is a plethora of UX evaluation methods (UXEM), but there is no gold standard method for evaluating UX. A collection of existing methods from academia and industry can be found in the "All about UX" website[30]. There is an advanced search functionality where methods can be found according to several criteria. For instance, searches can be made based on the type of study (e.g. field, lab), the development phase of the interactive artefact (e.g. prototype, product on market), the studied period of experience (e.g. before usage, long-term UX), evaluator/information provider (e.g. UX experts, groups of users), type of data to be collected (e.g. quantitative, qualitative) and application type (e.g. web service, hardware design).

Beyond evaluation methods, UX models, theories and representations are required to capture and communicate ideas about designing for and evaluating UX [69]. In fact, for the work in this thesis, the starting point was the study of the existing UX models, and then the UX evaluation methods were chosen according to the UX dimensions of the reference model and the requirements of the study.

Although there have been efforts to better understand the UX dimensions and the relationships among them, there is no standard UX model. Only a few models have been proposed, for instance the most comprehensive ones so far are the UX model [48] and the CUE-Model [111].

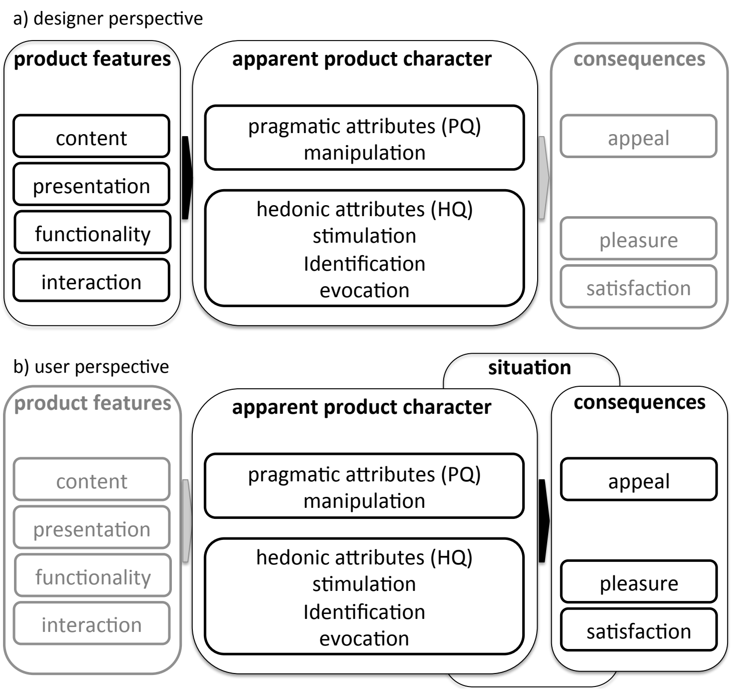

Figure 2.4: Key elements of UX model from a designer and user perspective [48].

30 http://www.allaboutux.org/all-methods

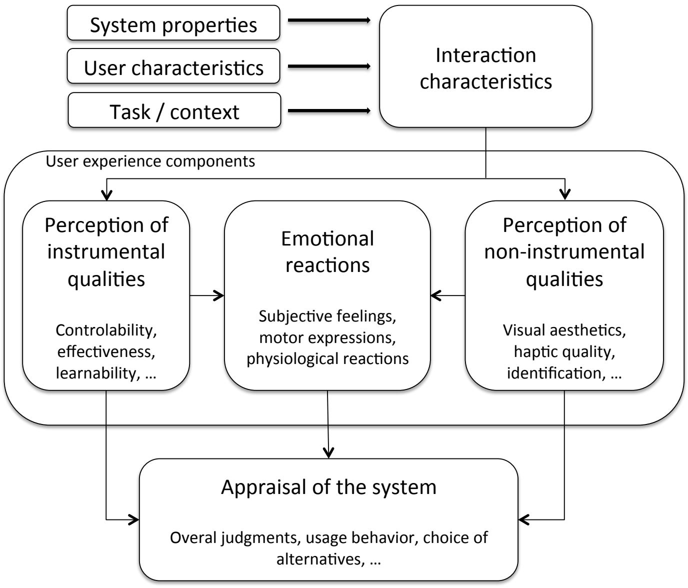

Figure 2.5: Components of User Experience (CUE) model [111].

The UX model proposed by Hassenzahl [48] (see Figure 2.4) separates the designer's perspective from the user's point of view. It is interesting to see that an artefact has certain features (related to content, presentation, functionality and interaction), which were chosen by the designer. On the other side, as a result of interacting with the artefact, the user perceives its features, probably in a different manner in which the designer conceived them. This personal vision of the user about the features of the artefact consists in both, instrumental and non-instrumental attributes (so-called pragmatic and hedonic respectively). While instrumental qualities are closely related to the perceived usability, non-instrumental ones are more related to the user's self. Based on those attributes the user is able to make judgements about the appeal of the artefact. In addition, emotional reactions (such as satisfaction and pleasure) may arise as a consequence of the interaction with the artefact.

According to the CUE-Model [111] (see Figure 2.5) the UX is comprised of three main elements: the perception of instrumental qualities (e.g. the effectiveness of a system), the perception of non-instrumental qualities (e.g. aspects that concern to the look and feel of the system) and the user's emotional responses to the system behaviour. The model suggests that user's perception of the two distinct types of qualities (instrumental and non-instrumental) may affect the third component of the model, that is, the emotional reactions of the interaction process. Similarly, it is probable that the three main elements of UX influence the overall appraisal of the system and thus, user's future behaviour.

Both models share the same foundations, as both describe UX based on instrumental and non-instrumental quality perceptions, and also include the emotional reactions of users and the appraisal or evaluation of the artefact.

UX and web accessibility

While researchers have investigated for years how to develop more accessible websites for users with disabilities, it is unclear the extent to which compliance with accessibility improves the user experience.

According to a survey conducted by Yesilada et. al in which over 300 people with an interest in accessibility took part, in general individuals claim that both qualities, web accessibility and UX, are strongly related [125]. Participants also believe that accessible sites benefit the experience of all users and particularly of those who are disabled. Web accessibility is also considered to be a subset of UX. So far, there are very few research works in the literature relating UX dimensions and web accessibility. One exception is an empirical study [80] that reports evidence on the relationship between aesthetic features and accessibility. In this case web accessibility was assessed by the Barrier Walkthrough [16] method focusing on people with visual impairments. Results showed that only one dimension of aesthetics (visually clean) was significantly related to web accessibility. That is, authors found that web pages judged on the classical aesthetics dimension as being visually clean showed significant correlations with web accessibility. Even if web accessibility was evaluated focused on barriers that could affect people with visual impairments, the aesthetic judgements were from sighted users. This suggests that a more comprehensive understanding of the relationship between web accessibility and UX is required.

In addition, the experiential and subjective quality of web accessibility remains barely unexplored. Understanding the interplay between the user experience (UX) and web accessibility is key to design websites that, beyond access, can provide a better UX for people with disabilities.

2.6 Conclusions

In this chapter, a review of research on web accessibility has been presented. Starting from its definition, existing guidelines and evaluation methods have been analysed. With the advent of the mobile web and ubiquitous access to the Web, the interaction context of users could greatly influence the interaction and the accessibility of web-based user interfaces. The results of the review suggest that automated web accessibility evaluation tools tend to produce generic results, as they do not take the interaction context of users (such as access device features) into consideration. The next chapter will be focused on this topic.

The ubiquitous manner in which the Web and web-based services can be accessed today, makes it difficult that a single design can be accessible for all potential users with any of the multiple access devices that exist today. Even the use of accessibility guidelines does not ensure that a user interface will be accessible for all end-users. Another way of addressing the "access for all" paradigm is by the use of adapted user interfaces. In the web environment, adaptation approaches have been the most employed technique. When it comes to ubiquitous services though, user interfaces can be automatically generated from an abstract description. Therefore, instead of adapting an existing interface, an adapted user interface can be automatically generated to cater the needs of users with disabilities. The review suggests that there are not many examples of automated user interface generators oriented to improve the accessibility for people with disabilities. Chapter 4 will address this issue.

The review on the topic of User Experience reveals that whether accessible or adapted user interfaces provide users with disabilities with an enhanced interaction experience is still unknown. In fact, very few studies explicitly explore the effect of web accessibility on UX. Chapter 5 will report empirical investigation on the relationship between these two constructs.

Chapter 3

Automated device-tailored mobile web evaluation

As the Web started to evolve to a more mobile access, the community started to acknowledge the limitations of the mobile web. Mobile users were considered as having situationally-induced impairments and disabilities (SIIDs), as they found similar problems as those faced by people with disabilities when navigating the Web. With the aim of providing guidance in the community, the W3C published the Mobile Web Best Practices 1.0 (MWBP 1.0), which should be followed so that websites to be deployed in mobile devices could provide users with a satisfying interactive experience. Some evaluation tools were developed to validate the mobile friendliness of the content of web pages in relation to the best practices. Nevertheless, since mobile devices had so different technical profiles, the results of the evaluations of websites (according to those mobile tests) were based on a generalisation of a common profile (so called Default Delivery Context, DDC). Users accessing a website from mobile devices with different features though, would experience the interaction quite differently. In order to reduce this ambiguity and produce more reliable evaluation results, which were closer to the reality of mobile heterogeneity, a tool which evaluates websites taking into consideration the technical features of access devices was developed. Empirical data showed that more accurate and reliable evaluation reports are obtained when using the tool.

3.1 Introduction

The interaction between a user and a website is characterised not only by the user and the website, but also by the access device and the situation where the interaction occurs. This indicates that the access device can affect the navigation on a website. In fact, research has shown that users without disabilities accessing the mobile web can experience similar difficulties to users with disabilities accessing the Web [123], [47], [122]. Mobile users can be considered as having situationally-induced impairments and disabilities (SIIDs) [102]. General accessibility guidelines (such as WCAG) are a valuable instrument for guiding web designers and developers in creating websites that are most likely to be accessible. Nevertheless, as general purpose guidelines do not consider the particularities of the access device of users, the resulting reports of evaluations may not be very reliable, and therefore not useful from the perspective of end-users.

The lack of awareness about the features of the access device when it comes to web accessibility evaluations may lead to unreliable reports. User characteristics and technological requirements are part of the "context of use" which has to be captured in order to obtain acceptable accessibility levels [106]. By having the possibility of adapting the accessibility evaluations to the characteristics of the access device of users, more reliable evaluations could be obtained.

3.2 Device-tailored evaluation framework

As a proof of concept of how mobile web evaluations can be tailored to accommodate information about the access device of users, a tool for device-tailored evaluations has been developed.

3.2.1 Methodology

The methodology followed to create the framework for device-tailored mobile web evaluations is based on these steps:

Gather and compile guidelines

The focus for this work was on guidelines oriented to delivering web content to mobile devices. In order to raise awareness in the community and provide guidance, the W3C Mobile Web Initiative published Mobile Web Best Practices 1.0 (MWBP 1.0) by Rabin and McCathieNevile [93]. Aiming at accurately and unambiguously deploy mobile web guidelines into evaluation tools, two test sets were defined: mobileOK Basic Tests 1.0 [85] and the supposedly more demanding mobileOK Pro Tests 1.0 [99]. Therefore, mobileOK tests were regarded as the techniques to precisely implement Mobile Web Best Practices at a different demand level. Those were the existing accessibility guidelines with regard to mobile devices available by the time that this research work was conducted. Since then, other guidelines have been released, for example the BBC Mobile Accessibility Standards and Guidelines[1], the Mobile accessibility guidelines[2] by Funka, or even the WCAG 2.0 applied to the mobile web content as described by the W3C [3]. In order to include these guidelines into the framework, the same steps that are described in this section should be followed.

Classify and order the set of guidelines

Three guideline sets (MWBP, mobileOK Basic and Pro) were analysed to identify the device dependencies and gather them into a document[4].

Usable screen width: 120pixels, minimum.
Mark up language support: XHTML Basic 1.1
Character encoding: UTF 8
Image format support: JPEG, GIF
Maximum total page weight: 20 KB
Colours: 256 minimum
Style sheet support: CSS Level 1
Scripting is not supported

Figure 3.1: Characteristics of the DDC.

As capabilities of most devices differed from those defined on the DDC, relying on the DDC dramatically reduced tool effectiveness, as far as automated evaluation was concerned. In this regard, two different problems were identified when it comes to web accessibility evaluation:

- False positives are those problems detected which are not actual is-

[1] http://www.bbc.co.uk/guidelines/futuremedia/accessibility/mobile
[2] http://www.funka.com/en/our-assignments/research-projects/archive---research-projects/mobile-accessibility-guidelines/
[3] http://w3c.github.io/Mobile-A11y-TF-Note/
[4] http://sipt07.si.ehu.es/nrhm/mobileokprotests.pdf

sues. Devices with more advanced capabilities are able to handle numerous data formats, support scripting, etc. Therefore, a tool assuming that these devices cannot deal with such issues will produce false positives. For instance, these types of problems arise when the mobileOK Basic test "3.22 Tables Alternatives", which warns about the use of table elements in web pages, is applied. The DDC based evaluation would return a warning even if a device actually supports tables. Another example of false positives related to the mobileOK Basic tests is "3.8 Image maps", which if an image map is found an error will be returned by the DDC based evaluation, even if the device can deal with them.

- False negatives are those undetected but real issues. All devices were supposed to meet the DDC, including those that have fewer capabilities, thus, false negatives are produced. Even nowadays, in the era of the smartphones, there are still "dumb" phones available in the market, which are basic phones with low end features (i.e. Nokia 215 model). For instance, when "3.4 Content format support" mobileOK Basic test is applied, it will be assumed that a given device supports JPEG or GIF picture format. The DDC based evaluation would miss those issues produced by devices that actually do not support these formats.

Obviating these problems would cause a decrease on the effectiveness of the evaluation tools, which is defined in terms of completeness, correctness and specificity by Brajnik [15] . Therefore, the best practices were analysed in order to identify the dependencies they had with regard to device features, and guidelines were modified in order to accommodate those dependencies.

Develop a computational representation of the guidelines

A computational representation of guidelines is necessary so guidelines can be managed by software components. In this case the guideline representation has to deal with the corresponding identified device dependency. These dependencies have to be represented in a generic way so they can contain a specific value that corresponds to the feature of a particular device. This is done by means of a RDF-based vocabulary that captures the concepts corresponding to the device dependencies. Some of the concepts represented in this vocabulary were reused from existing vocabularies (e.g.

UAProf[5] by the Open Mobile Alliance[6]).

3.2.2 Architecture

Based on the previously mentioned steps, a tool for mobile web guidelines evaluation was developed. It was implemented as a web application that allows to perform device tailored evaluations. The components of the application are described below (see Figure 3.2).

1. *Source Code Retriever.* This component obtains the (X)HTML code of a given resource in the Web. It can simulate the access of a determined mobile device to obtain the web content a particular mobile device would get. This is achieved by modifying the "User Agent" HTTP header with the information of an specific device model. By means of the User-Agent header, the client software originating the request is identified. In HTTP, the User-Agent string is often used for content negotiation, where the origin server selects suitable content for the response based on the known capabilities of a particular version of client software.

2. *Device Information Retriever.* This component obtains information about the software and hardware features of the requested device model from heterogeneous Device Description Repositories (DDR). Three data repositories, that were open at the time research was conducted, were used for such task.

   - The UAProf (User Agent Profile) specification from the Open Mobile Alliance are CC/PP based profiles with their own vocabulary defined through the *prf* namespace.
   - WURFL[7] (Wireless Universal Resource File) was a DDR that contained information about the capabilities of mobile devices and the browsers running on them. It was represented in a XML file called *wurfl.xml*.
   - DeviceAtlas (which is now a product from dotMobi) was a DDR where device data was available and packaged in JSON format.

   The fact that the file format and the underlying semantics (RDF, XML and JSON) were different for each repository was a challenge for the

[5] http://www.openmobilealliance.org/tech/profiles/uaprof/ccppschema-20021212

[6] http://openmobilealliance.org/

[7] http://wurfl.sourceforge.net/

interoperability among different sources of information. In order to overcome this issue, an abstraction layer was developed to deal with data in different repositories using different APIs. Therefore, the *Device Information Retriever* deals not only with the heterogeneity, but with completeness issues. Once the necessary data for a particular device model is obtained, a CC/PP compliant file is automatically created with the information about the features of the selected device.

3. *Guidelines Instantiator.* The information obtained from the *Device Information Retriever* in CC/PP format is used to enrich the mobileOK tests. So, the *Guidelines Instantiator* automatically updates the generic guidelines templates (implemented in XQuery) with the particular values of the mobile device. Therefore, device dependencies of best practices are removed by the inclusion of the actual features of the particular device model into the guidelines implementation.

4. *Evaluation Engine.* The (X)HTML of the web resource, obtained by the *Source Code Retriever*, is evaluated against the generated XQuery statements, which represent the guidelines enriched with particular device features. As a result of the evaluation, device-tailored accessibility reports are obtained. Since reports are XML based, other components can exploit the data to collect statistics, to keep track of the accessibility level or to automatically calculate accessibility scores.

3.2.3 How the application works

The previously explained components conform the device tailored evaluation framework, which was implemented as a web application (see Figures 3.3,3.4). It offers several possibilities for developers for evaluating a website: mobileOK Basic and mobileOK Pro guideline sets can be selected in two versions, the ordinary version (according to the DDC), and the enhanced version that considers specific device features. For this latter option, in addition to the URL of the website to evaluate, a mobile device model has to be chosen from a selection list. Once the "Evaluate" button is activated, a report is automatically generated and presented. This evaluation report shows a detailed list of the errors and warnings found by the application on the specified URL according to the selected guidelines.

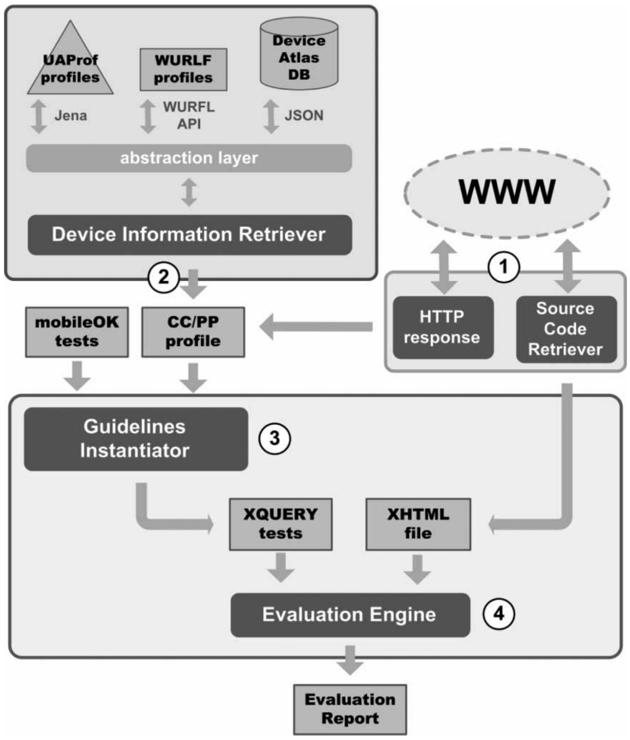

Figure 3.2: Architecture of the framework for device-tailored accessibility evaluations.

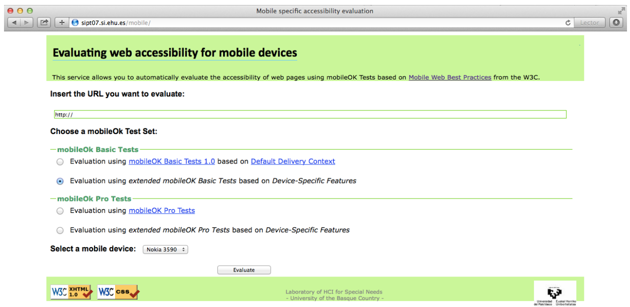

Figure 3.3: Main user interface for the device-tailored accessibility evaluation framework.

3.2.4 Case study

A case study was conducted with the aim of assessing the effectiveness of the tool when evaluating the accessibility of websites considering the particular features of specific devices. A number of web pages from eleven popular websites were evaluated against three mobile device models. Those threes were selected based on their characteristics with regard to the DDC.

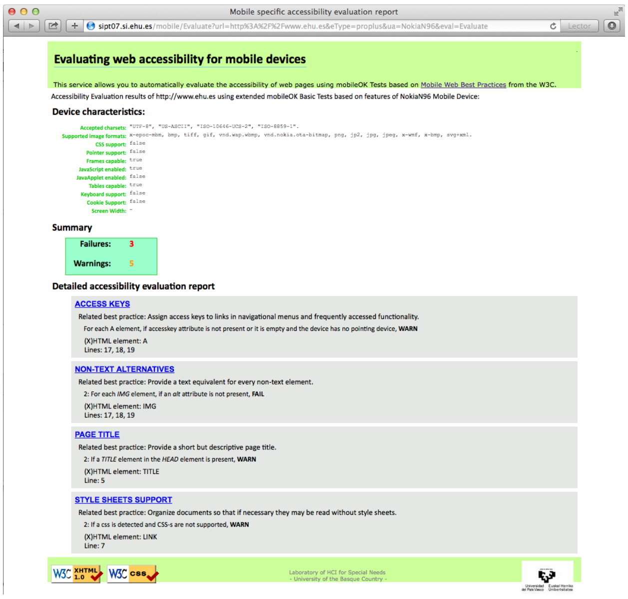

Figure 3.4: Detailed device-tailored accessibility evaluation report.

The first mobile model (D1:Nokia 3590) had worse features than the DDC, the second one (D2: Samsung SGH-E100) was similar to the DDC and the last device (D3: Sony Ericsson P990) had better capabilities than those specified in the DDC. Table 3.1 (see the first column) shows how those devices support the specific device-dependent features of mobileOK tests. For instance, browser issues such as the support for CSS, frames, tables or JavaScript.

Features	Namespace	mobileOK Basic	mobileOK Pro
Browser issues			
XHTML support	access xhtmlSupport	LINK-TARGET-FORMAT	
CSS support	access cssSupport	LINK-TARGET-FORMAT	STYLE-SHEETS-SUPPORT
Supported pictures format	access picFormatSupport	CONTENT-FORMAT-SUPPORT IMAGE-MAPS LINK-TARGET-FORMAT	
Accepted charsets	prf CcppAccept-Charset	CHARACTER-ENCODING-SUPPORT	
Frames supporting browser	prf FramesCapable	NO-FRAMES	
JavaScript support	prf JavascriptEnabled	OBJECTS-OR-SCRIPT	OBJECTS-OR-SCRIPT
Java applet support	prf JavaAppletEnabled	OBJECTS-OR-SCRIPT	
Multi-window support	access mwSupport	POP-UPS	
Tables support	prf TablesCapable	TABLES-ALTERNATIVES	TABLES-SUPPORT
Cookies support	access cookiesSupport		COOKIES
Device issues			
Pointing device support	access pntSupport		ACCESS-KEYS
Querty keyboard support	access quertyKeyboard		AVOID-FREE-TEXT
Screen width	access screenWidth		SCROLLING

Table 3.1: Browser and device dependencies with regard to mobileOK tests.

Table 3.2 shows the results of evaluation of different web pages against the mobileOK Basic and mobileOK Pro tests. In this case, only the DDC has been considered, no device-specific feature has been taken into account. The first column contains the URL of the web page and the subsequent ones show the accessibility issues found when using different guideline sets: mobileOK Basic and mobileOK Pro.

		mobileOK Basic		mobileOK Pro	
Item	URL	warnings	errors	warnings	errors
1	`http://www.google.com`	8	2	2	2
2	`http://www.youtube.com`	8	3	7	1
3	`http://www.flickr.com`	12	3	9	4
4	`http://www.amazon.com`	18	7	7	2
5	`http://www.gmail.com`	9	4	10	11
6	`http://www.facebook.com`	13	1	7	3
7	`http://m.flickr.com`	11	3	11	3
8	`http://m.yahoo.com`	18	1	6	5
9	`http://m.twitter.com`	18	2	14	6
10	`http://wapedia.mobi`	2	17	1	2
11	`http://www.wikipedia.org`	99	623	402	84

Table 3.2: Evaluation results when following the DDC specification.

The first six websites (range 1-6) correspond to the automatically redirected mobile version of websites. The second set of URLs (range 7-10) correspond to the separate mobile version of the websites. A traditional web page designed for desktop computers was also chosen (item 11) to observe different behaviours. The main difference between the mobile versions and the traditional websites is the number of problems found on them, as the latter are far more complex and thus contain more source code.

		D1		D2		D3	
Item	URL	warnings	errors	warnings	errors	warnings	errors
1	`http://www.google.com`	9	3	5	6	3	9
2	`http://www.youtube.com`	1	10	1	11	1	10
3	`http://www.flickr.com`	4	12	13	63	13	57
4	`http://www.amazon.com`	3	23	3	23	3	23
5	`http://www.gmail.com`	4	5	4	9	4	5
6	`http://www.facebook.com`	8	6	8	5	8	5
7	`http://m.flickr.com`	4	11	4	12	4	11
8	`http://m.yahoo.com`	3	16	3	16	3	16
9	`http://m.twitter.com`	7	5	7	13	7	5
10	`http://wapedia.mobi`	0	23	0	24	0	21
11	`http://www.wikipedia.org`	284	376	284	391	284	321

Table 3.3: Evaluation results of mobileOK Basic tests when specific device features are considered.

Table 3.3 contains evaluation results for the same web pages, but in this case the specific features of each device model were taken into account. The last three columns correspond to the warnings and errors detected using the mobileOK Basic Tests for each of the above-mentioned devices. It can be observed that these results from device-tailored evaluations, clearly diverge from those in Table 3.2 when specific device features were not considered.

Specifically, the guidelines that make a difference are both related to the support of picture, mark-up and style sheet formats (CONTENT-FORMAT-SUPPORT and LINK-TARGET-FORMAT). DDC-based results (removing item 11) have 11.7 warnings on average, while D1-tailored ones obtain fewer warnings: M=4.3; t(9)=-4.53; p=0.001. Similarly, D3-tailored evaluation yields fewer warnings: M=4.6; t(9)=-4.3; p=0.001. When it comes

		D1		D2		D3	
Item	URL	warnings	errors	warnings	errors	warnings	errors
1	`http://www.google.com`	6	12	2	6	5	12
2	`http://www.youtube.com`	5	6	5	7	5	6
3	`http://www.flickr.com`	8	10	30	70	29	68
4	`http://www.amazon.com`	7	19	7	19	6	19
5	`http://www.gmail.com`	6	13	6	17	5	13
6	`http://www.facebook.com`	7	8	7	8	6	8
7	`http://m.flickr.com`	8	9	8	10	7	9
8	`http://m.yahoo.com`	5	23	5	23	4	23
9	`http://m.twitter.com`	6	8	6	16	5	8
10	`http://wapedia.mobi`	2	20	2	23	2	20
11	`http://www.wikipedia.org`	335	357	335	421	334	354

Table 3.4: Evaluation results of mobileOK Pro tests when specific device features are considered.

to errors, DDC-based results produce an average of 4.3 issues. In general, device-tailored reports contain more errors: M=11.4, t(9)=4.32, and p=0.001 for D1; M=18.2, t(9)=2.63, and p=0.02 for D2; and M=16.2, t(9=2.41, and p=0.03 for D3. It can be concluded that in the case of mobileOK Basic tests uncertainty is removed because fewer warnings are produced and the number of errors increases in a significant way. Table 3.4 shows the same evaluations, but this time against the mobileOK Pro tests. When comparing device-tailored mobileOK Pro tests with DDC-based evaluation (removing item 11) it is concluded that device-tailored evaluation is capable of finding more errors. DDC-based reports contain in average 12.8 errors for D1 (t(9)=4.36, p=0.01), 19.9 for D2 (t(9)=2.72, p=0.02), and 18.6 for D3 (t(9)=2.51, p=0.03). Therefore, when mobileOK Pro tests are tailored to a particular device more errors are found. Since these errors were obviated by the DDC-based evaluation, it is concluded that the number of false negatives are dramatically reduced if device features are considered.

3.3 Conclusions

In this chapter an evaluation tool which deals with device features has been introduced. The guidelines were included into the tool after having being analysed (to identify dependencies with device features) and having being adapted (so they were able to incorporate specific features of devices). Information on the capabilities of different devices is retrieved from the available data device repositories and modelled into CC/PP profiles. The information about the features of the device is included from the profiles into the guidelines to complete them. As a result of evaluating websites according to guidelines which take into consideration specific feature of devices, device-tailored evaluation reports are obtained.

Results show that in the case of device-tailored evaluation of mobileOK Basic tests set, fewer warnings are yielded. This entails that the noise produced by false positives is significantly removed, which contributes to increasing tool correctness. False negatives are minimised because device-tailored evaluation finds more actual errors than the DDC-based evaluation does. Similarly, device-tailored evaluation of mobileOK Pro tests does also reduce false negatives since more errors are encountered. The decrease in false negatives also contributes to improve tool correctness. Furthermore, the application of mobileOK Pro tests leads to obtaining higher degrees of specificity. From a tool effectiveness point of view, empirical data show that the tool reduces the number of false negatives since more problems are encountered, which has a considerable impact on correctness.

Mobile technology evolves at a dramatically fast pace and it has changed tremendously since this research was conducted. Although the features of the current smartphones have overpassed the ones specified on the DDC, there is a wide range of basic mobile phones yet, and best practices still contain dependencies with device features that should be addressed by device-tailored accessibility evaluations. In addition, the followed methodology for the incorporation of device information in the automated process of evaluation is flexible in that is valid and applicable for past, present and future devices, and even for sets of guidelines that may be released.

Chapter 4

Automatic generation of adapted user interfaces

Considering that the Web can be accessed not only from computers or smartphones, but also through a wider range of consumer electronics, this ubiquitous access to the Web makes it difficult that a single design can accommodate the needs of all potential users. This would require applications that automatically adapt user interfaces to the needs of users, device capabilities and environmental conditions. In this chapter Egoki is presented, which is an automatic generator of accessible user interfaces designed to allow people with disabilities to access ubiquitous services. Egoki follows a model-based approach where suitable interaction resources and modalities are selected depending on the capabilities of users. The results of the evaluation showed that the adapted user interfaces automatically generated by Egoki were fully operable.

4.1 Introduction

The design of a unique user interface can hardly cope with the features of a ubiquitous web access and satisfy the needs of all the potential users. Even if general purpose accessibility guidelines are applied, these guidelines usually follow a design for all approach, and compliance to them does not always ensure the accessibility for each user due to the diversity of interaction contexts. This would require applications that automatically adapt user interfaces to the needs of users, device features and environmental conditions. As the Web as we know it today is a universe of applications and interconnected websites (which differ in structure, purpose, type of content, etc.), as a proof of concept of such an application, it was decided to start from ubiquitous environments. Two of the main reasons were that user interfaces are simpler in comparison to websites and context information is available for adaptation purposes.

In recent years, the advances in mobile technology and wireless data networks have allowed the development of the supportive ubiquitous computing concept. One of the most important characteristics of ubiquitous computing is context awareness. According to Dey, a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task [34]. Through this ubiquitous technology which is based on context awareness, users carrying their own smartphones are able to access locally provided services by means of their own devices. In addition, context-awareness technology allows announcing available ubiquitous services directly to the users through their devices, as soon as they enter a ubiquitous environment. If a user wants to use one of these services, a service-specific user interface will be rendered into his or her mobile device, and that user interface will enable the user to interact with the service.

The user interfaces provided for the services which are available in ubiquitous computing environments, usually are generic UIs. Therefore, people with disabilities can encounter accessibility barriers when trying to use them. In order to avoid these accessibility problems, ubiquitous service providers ideally should implement different UIs for each group of users who experience access restrictions. However, in practice this solution multiplies the design and maintenance workload. Alternatively, a model-based automatic UI generation approach has many potential benefits, especially in the case of ubiquitous architectures. This may be beneficial not only for the service designers, who will not have to deal with the creation of different versions of a UI, but also for the end-users, who would have the chance to use ubiquitous services in a more enhanced way. For instance, users with specific disabilities would be able to buy transport tickets, to control elevators, or to use ATMs from their own device and without the accessibility challenges that these machines or services usually entail for them. An interface generator that automatically creates UIs adapted to different user needs is herein presented. The interface generator system (Egoki) makes use of a formal description of the service, and information about the interaction context of the users, to generate automatically UIs adapted to their needs. The Egoki system was developed by the members of the Egokituz laboratory[1] based on the knowledge and expertise gained from the research work the laboratory conducted in the Inredis project.

As a member of the laboratory, I was actively involved in the design and development of the Egoki system. The main areas in which I particularly worked in were:

- Analysis of the requirements and design of the architecture of the system.
- Design of the models.
- Implementation of the UI generation process that transformed the abstract. user interface into an accessible and operable final user interface including transformation rules and adaptations.
- User testing.

4.2 The Egoki system

Egoki is an automated UI generator that creates adapted user interfaces for accessing services available in ubiquitous environments. Egoki creates UIs based on models. This paradigm differs from the more traditional one, which consists of designing a single UI for a particular service and eventually tailoring it to different groups of users. Egoki requires a logical description of the UI to specify the functionality of that interface in relation to the service. It also requires the provision and availability of suitable multimodal interaction resources. This way, accessible final interfaces can be automatically produced from these formal descriptions, as proposed on the Cameleon Reference Framework [25].

[1] Egokituz Laboratory: `http://egokituz.org/en/`

4.2.1 The ubiquitous environment

The application scenario of the Egoki system is composed of three types of elements: ubiquitous services provided by local automated machines (such as ATMs, information kiosks, and vending machines); a middleware layer that manages low-level interactions (between the ubiquitous system and the access device of the user); and users with mobile devices.

In this scenario, ubiquitous services are provided by applications running on locally available automated machines. This way, these services can be made available to users through mobile devices located within the local wireless network range. These machines are usually interconnected through heterogeneous wired and/or wireless networks. In addition, the services provided can have very diverse purposes; they may have been designed by different manufacturers, could be provided by different vendors and could run on devices with diverse capabilities. Therefore, a middleware layer is required to ensure interoperability among the elements of the ubiquitous environment. The middleware layer interconnects the diverse networks using different protocols, manages communications between devices, and integrates incoming mobile devices to the system by means of "discovery" mechanisms.

The middleware layer provides homogeneous methods to read and modify the state of the ubiquitous services. The Universal Control Hub (UCH) [126] was adopted to act as a middleware layer. Its implementation is based on the Universal Remote Console (URC) Standard [67]. This standard provides every user device with a unified access point to machines and services available in a network by means of a mechanism called User Interface Socket (UIS). The UIS describes the functionalities of devices and services in terms of abstract UIs.

4.2.2 Architecture of the Egoki system

The Egoki system is composed of three modules: the *knowledge base* (KB), the *resource selector* (RS), and the *adaptation engine* (AE). These interact with each other to process the inputs of the system and generate the corresponding adapted user interface (As shown in Figure 4.1). The KB module uses an ontology called Egonto[2] to store, update, and maintain the models regarding user abilities, access device features, and interface adaptations. The RS module queries the ontology to obtain the abilities of users and the features

[2] `http://sipt07.si.ehu.es/icearreta/AdaptiveOntology.owl`

of the device so that it can select appropriate resources for each user, mobile device, and service. It requires as inputs a logical specification of the UI and different types of interaction resources. The AE module performs the required transformations and applies the adaptation rules to generate the final accessible and user-tailored interface. More details about the architecture of Egoki can be found in [2].

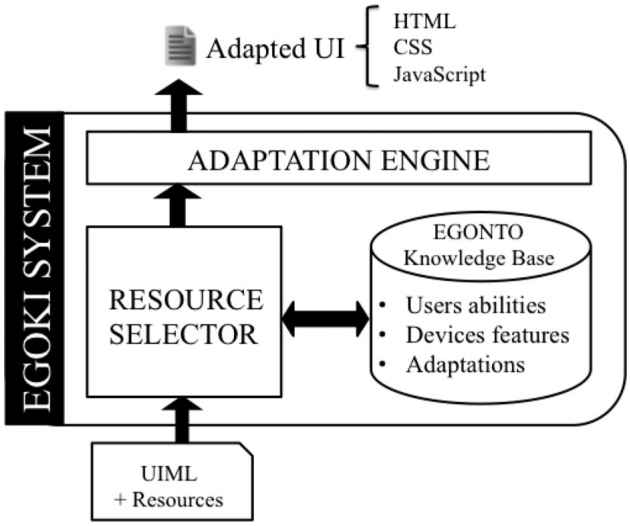

Figure 4.1: Architecture of the Egoki system.

4.2.3 Models

The models for the representation of users, devices, UI features and required adaptations, are the foundations which Egoki lays for the automatic generation of adapted UIs. This information is accessed through the *knowledge base* of the system. The Pellet[3] reasoner has been used for accessing the information from the KB, storing new data, and inferring information about the required adaptations. In addition to those models, a UI model has been defined to describe the functionalities (that have to be presented on the adapted user interface) of the ubiquitous services.

User model

The user model defined by the Egonto ontology is based on the interaction abilities of users. In particular, four general interaction abilities and

[3] http://clarkparsia.com/pellet

other specific ones have been included (see Figure 4.2), as explained in the following lines.

- Cognitive: Skills involved in human communication and in the interaction with technological devices: attention, concentration, concept formation, language processing, learning, memory, and perception [76].
- Physical: Mobility and speech related abilities were modelled as physical user abilities that influence the interaction with UIs. Regarding mobility, concepts such as brain motor area, precision, strength, and tactile sensation [79] were included. In the case of speech, context information about sound articulation and voice features were added.
- Sensory: Sight, hearing, and human touch senses were included because they are directly related to interaction abilities [112].
- Affective: Both the transmission and the interpretation of emotions are a key part of human communication and interaction. For instance, people who have affective disorders, such as Asperger syndrome, usually have communication problems (both verbal and non-verbal) [37].

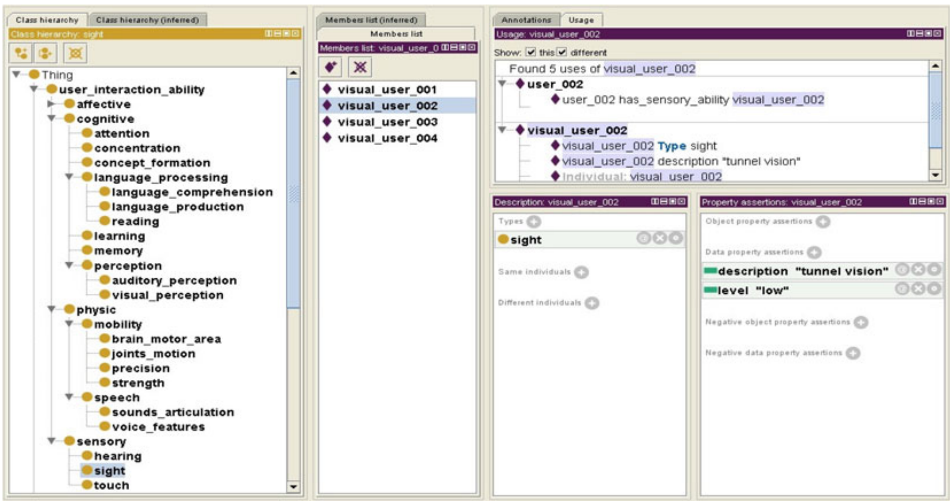

Figure 4.2: Screenshot of the Protégé browser of Egonto showing the user-model class hierarchy for an individual with tunnel vision.

The affective interaction ability is only considered in the representation of the user model, not in the application of the adaptations. Ontologies can represent knowledge of real-world domains using a large number of concepts, but it is often not necessary to use the whole model for all users or scenarios. For instance, in some cases, using the description of cognitive processes in detail will not be necessary for the UI generation. The "level" property (bottom right part of Figure 4.2) indicates the level of each ability within a specific scale. The scales for this property are similar to the measures of the ontology in [60]: High (H), Medium (M), Low (L), and Not Applicable (N/A). In some cases, it is sufficient to use general categories and simple concepts because the adaptation possibilities of a system are limited; whereas, in others (for instance, when it comes to vision or hearing impairments), using specific scales and metrics may allow a more fine grained adaptation approach. To this end, a field named "description" is included where a specific metric can be included to distinguish different abilities. For instance, for a user with low vision ("L" value of the "level" property in the sight sensory ability, see Figure 4.2), more specific information can be represented, such as "tunnel vision", "problems in colour perception" or "problems in distance perception" [60].

The abilities of users can also be combined to establish a more specific user profile. Consequently, it is possible to model users with combinatorial disabilities. The combination of user abilities is particularly useful for modelling characteristics of elderly people because they usually experience more than one type of restriction related to hearing, sight, motor skills, memory, and reasoning [79].

Device model

Device characteristics are also represented in Egonto (see the "a" part of the Figure 4.3) as the required adaptations may be different due to device-specific dependencies. For instance, the adaptations required by a smartphone user can differ from the adaptations required by a user with a tablet. In addition, accessibility is strongly linked to the preferred modality of the user. There are two types of general ontology classes in the device model (see the "a" part of the Figure 4.3):

- Hardware components: hardware-related features such as input/output devices; peripheral features (e.g. display resolution); interaction modes allowed (e.g. touch screen); battery autonomy; and wireless connectivity.
- Software components: information about the applications installed on the device. This includes web browser features, such as whether JavaScript is supported, which versions of markup languages can be interpreted, which formats are supported, and which assistive technology applications are installed on the device (e.g. screen reader,

face detection, or voice recognition).

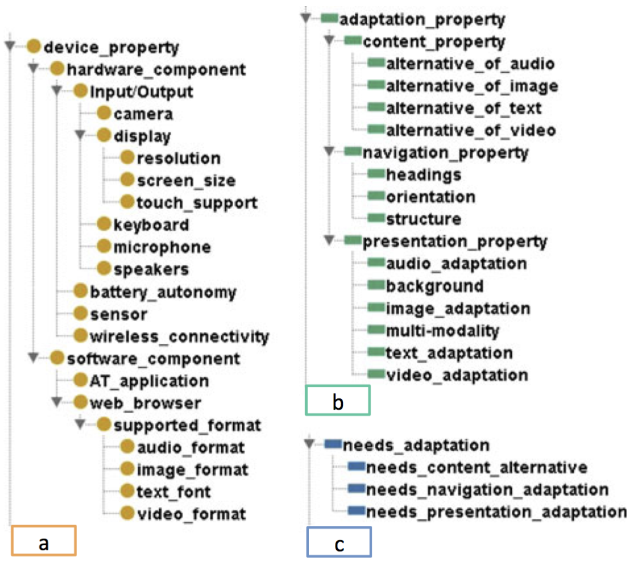

Figure 4.3: Screenshot of the Protégé browser of Egonto. (a) Device model class hierarchy. (b) Object properties for linking the user concept with the adaptation concept. (c) Data properties to indicate the scope of the adaptations.

Adaptation model

The adaptation rules were collected from different works found on the literature [84], [41], [65], [23], [96]. The adaptation taxonomy presented in [61] was used to group the adaptations. This taxonomy considers content, navigation, and presentation adaptations. The Egonto ontology follows this classification and includes these concepts to relate the abilities of each user with the most adequate adaptations. Figure 4.3(b) shows the properties for matching a user with the adaptations set, and Figure 4.3(c) depicts the properties that the ontology uses for indicating the scope of the adaptations.

The content adaptations performed by Egoki are based on selecting and including alternative resources if the user does not have the ability to use a specific media type. For instance, simplified text can be provided as an alternative to the usual text media type for people with reading difficulties. Four generic media types are described, and some alternative resources are indicated as a content adaptation for each of them. Some examples of alternative resources for each generic media type are listed below.

- Alternative for video media type: captions.
- Alternative for audio media type: transcriptions.
- Alternative for text media type: simplified text or pictograms.
- Alternative for image media type: pictograms or alternative text.

The user interface presentation is adapted through different parameters such as the font colour and size, the background colour, the size of images, or selecting high-contrast resources.

With regard to navigation adaptations, in some cases the UI can be divided into simpler UIs to support comprehension of the current task. When the task requires several steps, a possible navigation adaptation is to provide the user with a task sequence describing each step in detail.

Reasoning rules

The main role of the reasoning rules is to select the most appropriate adaptations for each user, based on the information on their profiles. Generic rules assign an initial profile to each user, and more specific rules allow a more fine grained adaptation level.

Reasoning rules were added into Egonto using the Semantic Web Rule Language (SWRL) [54], and they are applied from the *knowledge base* (KB) module using the Pellet reasoner. As an example, Figure 4.4 shows a generic rule for people with a high level of sensory and physical abilities and a medium level of cognitive abilities. The result of applying the reasoning rules is a set of interface adaptations to be applied by the Egoki system. Based on the previously mentioned analysis of the required adaptations, different SWRL rules were constructed and stored in the ontology to match the adaptation rules with user profiles. Having these rules in the ontology, Egoki will apply the corresponding rules to the specific abilities of a certain user. In this example, simplified text is required as an alternative resource to the text content because the reading level of the user is low. This adaptation facilitates comprehension of the functionalities as well as the content of the UI.

User interface model

Egoki requires a middleware as a remote interface for the ubiquitous system, and a logical description (which is platform independent) of the UI

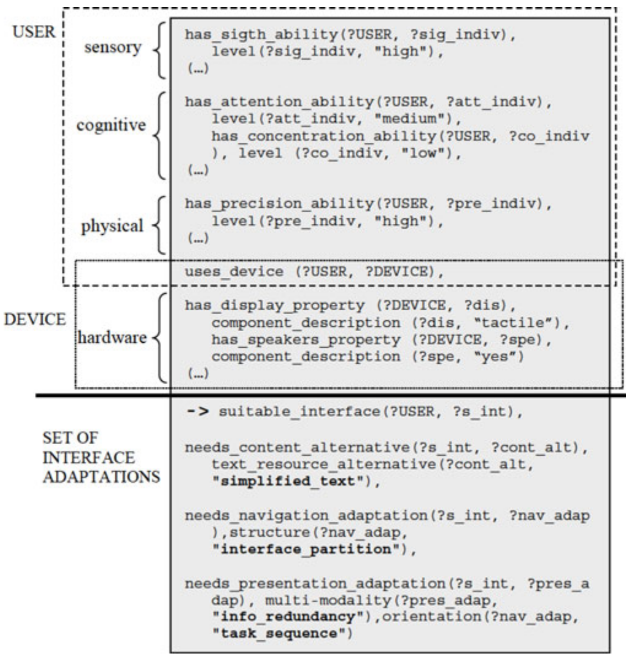

Figure 4.4: Screenshot of a SWRL rule showing a reasoning rule that assigns a suitable adaptation set for specific communicative abilities and device access features.

for describing the functionality of each ubiquitous service. The URC/UCH middleware was adopted as a remote interface with the ubiquitous system; and UIML was used as the platform independent description of the UI of the services. A number of user-interface description languages such as UsiXML [74] and MARIA [88] were analysed. Finally UIML was adopted, due to its flexibility with regard to including user interface resources.

UIML is an XML-based language that provides elements and attributes for defining the structure, content, and behaviour of a UI (see Figure 4.5). Nevertheless, this language does not provide direct mechanisms for defining some necessary elements, such as dependencies between functionalities of the service and interaction elements of the UI. It also lacks a way to set priorities for the different alternatives of types of resources. However, it is flexible enough to be extended by means of a specific vocabulary.

Therefore, an extension of UIML was defined to enhance its semantics. The new features included in the UIML vocabulary are described in the following lines. A ubiquitous service called "lunch menu selection" was used to illustrate them. For this purpose, excerpts of the code for this service are presented in Figures 4.6, 4.7 and 4.8.

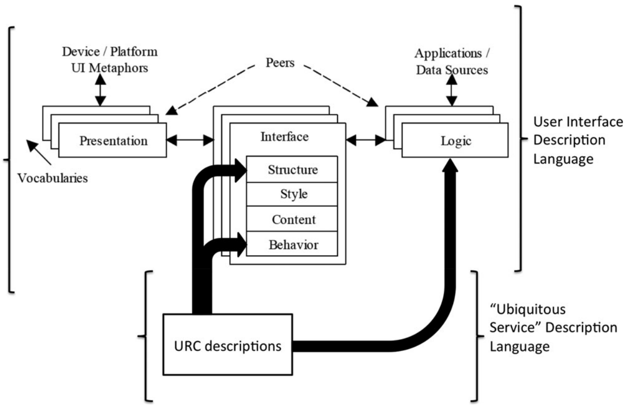

Figure 4.5: UIML metainterface model modified from [91].

```
<part id="FirstCourseSection" class="section">
    ...
</part>
<part id="SecondCourseSection" class="section">
    ...
</part>
<part id="DessertSection" class="section">
    ...
    <part id="DessertFunctionality" class="functionality">
        <part id="Dessert" class="select">
            <content id="priority">
                <constant id="text"  value="1"/>
                <constant id="image" value="2"/>
                <constant id="audio" value="3"/>
                <constant id="video" value="4"/>
            </content>
            <variable name="inputDessert"/>
            <part id="Dessert_a" class="item" source="Dessert_a"/>
            <part id="Dessert_b" class="item" source="Dessert_b"/>
            <part id="Dessert_c" class="item" source="Dessert_c"/>
        </part>
        ...
    </part>
    ...
</part>
```

Figure 4.6: Segment of code showing the definition of different types of resources for the "selecting a dessert" functionality.

- The *class* attribute of the *part* element in UIML is used for defining the type of interaction element. Possible values for this attribute are *section*, *select*, *item*, *button*, *outputData*, *boolean*, *inputData*, and *functionality*. The first value (*section*) is used to group related interaction elements so that they can be placed close to each other in the final UI. The *functionality* type is used to define parts of the interface as functionalities that are directly operated by users. The other elements identify the type of interaction elements included in the content. Figure 4.6 shows the description of a ubiquitous service called "lunch menu se-

```
<content id="text" >
 <constant  id="ref_text:Dessert_a"
            value="Fresh fruit apple"/>
     <constant id="ref_simplified_text:Dessert_a"
              value="Apple"/>
     ...
</content>

<content id="image" >
     <constant id="ref_image:Dessert_a"
              value="resources\menu\image\dessert_a.png" />
     ...
</content>

<content id="high_contrast_image" >
     <constant id="ref_high_contrast_image:Dessert_a"
              value="resources\menu\image\dessert_a_HC.png" />
     ...
</content>

<content id="audio" >
     <constant id="ref_audio:Dessert_a"
              value="resources\menu\audio\dessert_a.mp3" />
     ...
</content>
```

Figure 4.7: Segment of code showing the definition of different types of resources for the functionality of “selecting a dessert”.

```
<behaviour>
 <rule id="rule_Dessert">

  <condition>
   <event part-name="Dessert" class="change"/>
  </condition>

  <action>
   <call component-id="GuresareMeal" methodid="setDessert">
     <param name="setDessert_param1">
      <property part-name="Dessert" name="inputDessert"/>
     </param>
   </call>
  </action>

 </rule>
</behaviour>
```

Figure 4.8: Segment of code showing the definition of different types of resources for the functionality of “selecting a dessert”.

lection”. In this example, the service is composed of three *section* type elements specified by means of the *class* attribute. In the last *section* type element, a *functionality* type element is provided with a single *select* type interaction element with three options.

- Service providers can specify priorities for the different media types for each resource. Priorities must be set for each alternative of the interaction element represented in the UIML. They are specified by means of the *id* and attributes of the *constant* elements. Based on those values, Egoki can select the appropriate media types for all resources according to user, device, and service features. In Figure 4.6, the service provider has specified priorities for four different types of media resources (text-priority 1, image-priority 2, audio-priority 3, and video-priority 4).
- Different values have been defined for the *id* attribute of the *constant* element in UIML. This allows providing an alternative for a particular interaction resource: text, simplified text, video, image, high contrast image, audio, simplified audio, text transcription, and signed video. Figure 4.7 shows examples of different types of interaction resources.
- The data exchange between the Egoki system and the ubiquitous services is modelled in the *behaviour* section of UIML. The behaviour of UIs is described through *rule* elements. Some extensions have been made to the vocabulary to accommodate event-driven code generation. *Init*, *change*, and *select* are the events used for UI elements. Figure 4.8 shows the *behaviour* section of the *select* type element for selecting the dessert in the "lunch menu selection" service.

4.2.4 User adapted interface generation process

The automated generation of user-tailored interfaces is based on the transformation of a logical specification of a UI described in UIML into a final functional UI using the information specified in the models. The process that Egoki performs to generate automated user-tailored interfaces consists of three main phases: 1) querying models; 2) selecting resources and adaptations; and 3) constructing the final UI (see Figure 4.2).

1. The *resource selector* (RS) module parses the UIML document and retrieves the information on functionalities, including the media resource types for interaction elements and priorities. The RS module gets each *part* element of the UIML that contains a "functionality" value in the *class* attribute, as well as the child elements inside it.
2. The RS module queries the KB to obtain (a) specific type(s) of interaction resource to represent each functionality according to user and device features. See Figure 4.10, which shows the selection of the appropriate resource(s). As output from this phase, the RS module

provides the *adaptation engine* (AE) module with the list of specific resources, as well as all possible adaptations.

3. Finally, the AE module generates a functional final UI tailored to the needs of the user and device. The AE module applies several XSL transformations and CSS rules that correspond to the identified adaptations. There are three main types of transformations for different generation purposes: content, behaviour, and presentation.

   - Content: XSLT rules are used to transform logical UI descriptions specified in UIML into specific interaction elements in the HTML language. Figure 4.9 shows an excerpt of the HTML code generated for the "lunch menu selection" service, where the interaction element is composed of audio, text, and image resource types.

   - Behaviour: UCH middleware provides specific URLs in order to set and get the state of a particular ubiquitous service, which is used for defining the behaviour of the UI. This information is contained in the *peers* section of the UIML document (see Figure 4.5). The *behaviour* section identifies the functions triggered by each interaction element and the supported events. By means of specific XSLT rules the behavious of the final UI is implemented.

     – Step 1 (file generation): A JavaScript file is generated for each ubiquitous service.

     – Step 2 (event registration): The events supported by each interaction element are bounded to their correspondent HTML elements. This allows generating non-intrusive JavaScript code.

     – Step 3 (function generation): A JavaScript function is generated for each rule defined in the *behaviour* section. These functions get and set the states of the ubiquitous services. To this end, the URLs provided by the middleware are included in the function, which uses Ajax technology to communicate with the services.

   - Presentation: CSS rules are used to implement some style-related adaptations for accommodating user needs, for example, setting foreground and background colours, font styles and sizes, and space between UI elements.

By executing content, behaviour, and presentation transformations, the AE module is able to generate a web-based UI that is tailored to

```
<audio id="ref_audio:Dessert_a"
    preload="auto">

  <source type="audio/mpeg"
        src="resources\menu\audio\dessert_a.mp3"/>

</audio>

<input id="Dessert_a" type="radio" name="Dessert"
      value="Dessert_a"/>

  <label for=" Dessert _a">
    <img alt="Apple" src="resources\menu\image\dessert_a.png"/ >
    <span>An apple</span>
  </label>
</input>
```

Figure 4.9: Excerpt of the HTML 5 code generated by Egoki.

the user's needs. In addition, the UI allows the user to access and use the requested ubiquitous service. The markup language used in the final UI will mainly depend on the requirements of the access device.

```
For each functionality of the service
1-Select the media type with the highest priority
2-Query the ontology about the suitability of this
     media type for the specific user and his/her
     device or the need for an alternative resource
If the media type is not appropriate and an
     alternative is not provided:
select the media type with the next highest priority
     and go to step 2 again
Else select the resource associated with this media
     type and go to step 3
3 - Query the ontology about the adaptations
     required for that media type according to the
     user's ability levels and access device
     features.
```

Figure 4.10: RS module algorithm for selecting appropriate resource(s) for a given user.

4.2.5 Implementation

The Egoki system was developed using the Eclipse version for Java EE developers[4]. Egoki is a Java web application compliant with JDK 1.6. Additional libraries include the following:

- Pellet and OWL API[5] for accessing ontology and inferring information by applying SWRL rules;

[4]http://www.eclipse.org/downloads/packages/eclipse-idejavaeedevelopers/keplersr2

[5]http://owlapi.sourceforge.net

- Apache Xerces[6] for parsing, manipulating and creating different XML documents;
- Apache Xalan[7], an XSLT processor for transforming XML documents to XML, HTML, or text;

The Egonto ontology was developed using OWL[8], and the rules included in Egonto are based on SWRL [54]. As mentioned, the final UIs are web interfaces based on HTML, and their behaviours were generated using jQuery[9] to manage UI events and Webclient Javascript library[10] to provide necessary interaction with the ubiquitous service.

4.3 Case study

In order to evaluate the operability and accessibility of the automatically generated UIs, two services were implemented using UIML specifications, and a set of multimodal resources for each interaction element was also created. Service 1 was a lunch menu selection service, and service 2 was a local bus information service. The lunch menu selection service offers the possibility to select a first course, a second course, and a dessert. The second service was a local bus information system to search for urban bus routes and schedules. Having the UIML and the associated resources for each service, Egoki is able to generate different versions of user interfaces to access and use those services, based on the information of the models.

With a formative purpose and with the aim of identifying a potential list of problems on the automatically generated interfaces, they were evaluated by means of different methods. Two methods of different nature (analytical and empirical) were employed. Firstly, the Barrier Walkthrough method [41] was used to manually identify potential accessibility problems; and secondly, informal tests were conducted to observe the real problems faced by users.

The interfaces for both services were evaluated for two user groups, blind users and users with cognitive disabilities. The user interfaces that Egoki generated for both services were different for both group of users (see Figures 4.11, 4.12, 4.13 and 4.14). These different UIs were automatically gener-

[6] `http://xerces.apache.org`
[7] `http://xml.apache.org/xalan-j/`
[8] `http://www.w3.org/2001/sw/wiki/OWL`
[9] `http://jquery.com`
[10] `http://myurc.org/tools/Webclient/`

ated by Egoki as a result of applying different adaptations for each service based on the models of each user group:

Figure 4.11: UI for selecting a dessert, created by the Egoki system for the first user group [Translation to English: "Menú" is "Menu", "Postre" is "Dessert", "Selecciona el postre" is "Select a dessert", "Flan" is "Creme Caramel"; "Menú de Navegación" is "Navigation Menu"; "Anterior" is "Back" and "Siguiente" is "Next"].

Figure 4.12: UI for selecting a dessert, created by the Egoki system for the second user group [Translation to English: "Menú" is "Menu", "Postre" is "Dessert", "Selecciona el postre" is "Select a dessert", "Flan" is "Creme Caramel"; "Menú de Navegación" is "Navigation Menu"; "Anterior" is "Back" and "Siguiente" is "Next"].

In the case of the first user group, content adaptation rules were based on the selection of "text" resources for each element of the interface (as text is the most suitable media type for screen readers). With regard to the navigation adaptation rules, headings were added to the interface ("heading inclusion" technique) and also, instead of presenting large amounts of information in just one UI, the information was split into a number of simpler

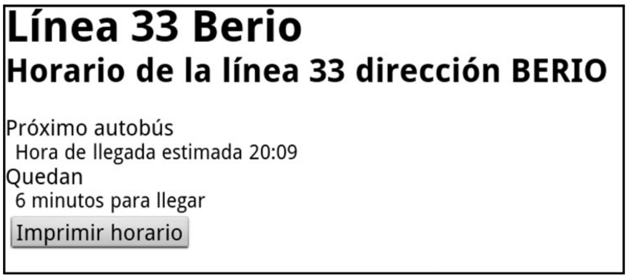

Figure 4.13: UI with the bus information obtained for the first user group [Translation to English: “Línea 33 Berio” is “Line 33 Berio” “Horario de la línea 33 dirección Berio” is “Schedule of bus line 33 bound to Berio” “Próximo autobus. Hora de llegada estimada 20:09” is “Estimated arrival time of next bus 20:09”; “Quedan 6 minutos para llegar” is “6 min to arrive”; “Imprimir horario” is “Print Schedule”].

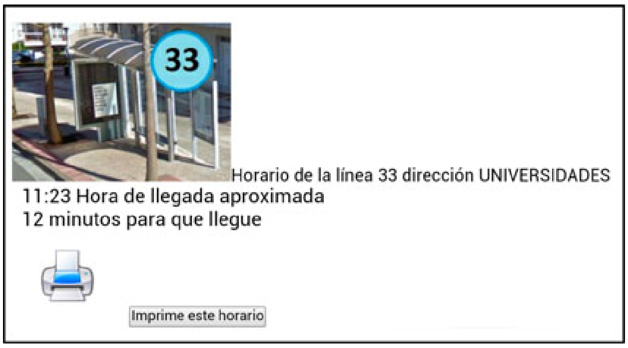

Figure 4.14: UI for local bus information service created by the Egoki system for the second group [Translation to English: “Horario de la l´ınea 33 dirección UNIVERSIDADES” is “Schedule of bus line 33 bound to UNIVERSITIES”; “11:23: Hora de llegada aproximada” is “Approximated arrival time 11:23”; “12 minutos para que llegue” is “12 min to arrive”; “Imprime este horario” is “Print this schedule”].

UIs (“interface partition”). Table 4.1 summarises the adaptation techniques applied for blind users.

In the case of the second user group the following adaptations (see Table 4.2) were applied based on the NI4[11] recommendations [84].

Content adaptations:

- The content of the user interfaces is hierarchically structured in order to maintain the attention of users.

[11] http://www.ni4.org/modules/Downloads/archivos/manuales/protocoloni4.pdf

	scope	adaptation rule
content	image media type alternative	"text"
	audio media type alternative	"text"
navigation	headings	"heading inclusion"
	structure	"interface partition"

Table 4.1: Adaptation techniques applied for blind users.

- Information redundancy is used for a better understanding of the content; that is, for each interaction element in the user interface, elements supported by other media types (image, audio and text) conveying the same information are added.
- In the case of textual resources, simplified text is used in order to assist the reading comprehension of people with cognitive disabilities.
- The information is provided grouped and outlined in order to help people with cognitive disabilities who have less memory capacity.

Navigation adaptation rules:

- Special components are included in order to provide task sequence and orientation information. These informative elements show the whole sequence of steps required to complete a task. The current step appears highlighted.
- Interfaces are also partitioned into simpler ones in order to simplify the interaction. To achieve this two types of navigation schemes have been considered:
  - Sequential partition for tasks that require a step by step interaction (e.g. the meal selection service).
  - Tree based navigation for services that show different information to the user based on their choice (e.g. the bus timetable service)
- Links such as "Previous Page" and "Next page" are used for navigating through partitioned user interfaces.

Table 4.2 shows the adaptation techniques applied for users with cognitive disabilities.

	scope	adaptation rule
content	image media type alternative	"info redundancy"
	text media type alternative	"info redundancy"
	audio media type alternative	"info redundancy"
navigation	orientation	"task sequence"
	structure	"interface partition"

Table 4.2: Adaptation techniques applied for users with cognitive disabilities.

4.3.1 Manual evaluation

In order to identify potential accessibility barriers on the automatically generated user interfaces, the Barrier Walkthrough (BW) accessibility inspection method [41] was employed. This method is an adaptation of the heuristic walkthrough method used for usability, where the principles are replaced by barriers. Even if the UIs that Egoki generates are not websites, as they are web-based UIs it was decided to employ this method.

Participants

Six people trained in accessibility took part in this evaluation. The interfaces for both services were evaluated for two user groups, blind users (group one) and users with cognitive disabilities (group two). Three people evaluated Services 1 and 2 for blind users, and the other three evaluated both services for users with cognitive disabilities.

Stimuli

The user interfaces of the previously described two services were used as stimuli: a lunch menu selection service (Service 1) and a local bus information service (service 2). See Figures 4.11, 4.12, 4.13 and 4.14. Two interfaces were evaluated for each service: an option selection interface and the confirmation interface.

Procedure

Evaluators were provided with the documentation required to perform the BW method, and each evaluator independently checked all barriers detected in the interfaces of both services. Then, they met and merged the detected barriers into a single list by assigning a single severity score to each barrier. Tables 4.3 and 4.4 summarise the results.

Results

Outcomes from the BW showed that all the barriers found were minor for the first user group (blind users). It was observed that all of the identified barriers were side effects of the application of the "interface-partition" adaptation. The purpose of that particular adaptation was twofold: first, to simplify the interaction (as Service 1 involves several steps to select a specific menu); and second, to address the dynamic content generated by the selection of dishes. As the adaptation offers advantages to the interaction with a screen reader, the hypothesis was that the adaptation would be favourable and would benefit users even if it introduced potential minor barriers.

first user group: blind users		
severity	barriers in service 1	barriers in service 2
minor	page without titles	-
	generic links	-
	non-separated links	-
significant		-
critical	-	-

Table 4.3: Accessibility barriers detected in both services for the first user group (blind users).

With regard to the second user group (participants with cognitive disabilities), no critical barriers were identified. It was observed that the barrier "no page headings" was present because the adaptation for including headings was not applied. This knowledge would be added to the Egonto KB if the results of the user evaluation showed that it was required. The barriers of "generic links" and "ambiguous links" (in service 1) were due to the application of "interface partition" adaptation, which included "back" and "next" links on each UI that was generated. The barriers of "complex

second user group: users with cognitive disabilities		
severity	barriers in service 1	barriers in service 2
minor	complex text	rich images lack equivalent text
	no page headings	acronyms without expansions
	missing icons	complex text
significant	rich image lack equivalent text	no page headings
	generic links	missing icons
	ambiguous links	
critical	-	-

Table 4.4: Accessibility barriers detected in both services for the second user group (users with cognitive disabilities).

text" and "rich images lacking equivalent text" are related to the provided resources, not to the Egoki system itself. The same applies to the "missing icons" barrier, which is related to the information requested from the service. As this information comes in real time, Egoki displays the information as provided by the service. If the service does not provide the information in different modalities, Egoki cannot create alternative resources dynamically. With regard to the "acronyms and abbreviations without expansions" barrier, because no acronyms or abbreviations were found on the generated UIs, that was not considered as a barrier.

4.3.2 User testing

Informal tests were performed with the objective of evaluating the operability of the generated UIs and to identify actual problems found by users.

Participants

Two user groups were recruited: blind users and users with cognitive impairments. A total of eleven participants took part in the study, two legally blind participants (a 29-year-old female and a 39-year old male) with a high expertise level with computers; and nine participants with cognitive disabilities (four females and five males within an age range of 27–43 years, median age 32).

Participants with cognitive disabilities worked at one of the shelter workshops of the Gureak Group[12] and had similar cognitive abilities: a medium level of attention, perception, language processing, learning and memory abilities; and a low level of concentration and concept formation level. This information was provided by their tutors. The level of expertise with computers varied among participants, two participants had little experience with computers, five of them claimed to have some experience and the remaining two admitted having extensive experience with desktop computers. However, they were not able to give the precise number of years of computer use.

Apparatus

In order to conduct the test the following devices were set up for the user testing sessions:

- A server where the Egoki system was installed, including all the multimedia resources associated with the ubiquitous services.
- A local network to make the ubiquitous services available.
- Two cameras to record the interaction of each user.
- A printer to print out the proof of task completion by participants.

Blind participants came with their personal laptop. Thus, the devices were already configured according to their preferences and needs. Both blind participants used the same model and version of the screen reader (JAWS v.12) but with different web browsers (Mozilla Firefox 4 and Internet Explorer 9).

Participants with cognitive disabilities used an off-the-shelf tablet with Android 4.0.3 operative system and Google Chrome web browser. A tablet was selected as the access device because using a touch-screen device was a recommendation from the tutors of the participants. The participants did not use any specific assistive technology for the test. However, the tutors, who usually help them to use technology in their workplace, accompanied all participants during the sessions. This was necessary in order to maintain efficient communication with the participants, as well as to provide support to the participants during the test sessions.

[12] `http://www.grupogureak.com/en/Default-en.aspx`

Stimuli

The previously described two services were used as stimuli: a lunch menu selection service (service 1) and a local bus information service (service 2). Figures 4.11, 4.12, 4.13 and 4.14 show the screenshots of the user interfaces.

Procedure

The user evaluation sessions were conducted on two different days and in two different locations. On the first day, the sessions with blind participants were conducted in a lab at the Faculty of Informatics at the University of the Basque Country. The sessions with participants with cognitive disabilities were carried out on a different day and in a room at the Gureak shelter workshop. Similar procedures were followed in both cases. Sessions were conducted one by one (one participant at a time) and in Spanish, the first language of all participants. Each session was started by providing the participant with the information about the study. After that, they were asked for their consent to record the session. They were asked some questions to collect demographic data (e.g. age and expertise on using computers, touch screens or screen readers). In the case of participants with cognitive disabilities who had never used a touch screen device, some explanations were given and they were allowed to try the tablet before starting the evaluation.

Following a within subject approach, all participants had to interact with both services and they were asked to perform the specified two tasks in both services. A counterbalanced approach was followed were the order in which services were presented to the participants was randomly alternated to avoid order effects. Two different tasks were defined for both services: the first one (task 1) was a pre-defined task (the participants had to select a given lunch menu or search for information on a particular bus line); and the second one (task 2) was a free task (they could select any option for lunch or search for information on any bus line). The first task was intended as a training task to allow participants get familiar with the services; while the second task was intended for allowing a more natural interaction with the service.

Each session started with the first task of the corresponding service. When the first task had been completed, the participant started on the second task. During the tasks participants were free to make any comment. When both tasks for a service had been completed, the participant was asked some questions. After that, the participant was asked to start with the other service in an analogous way.

In each session, the following data were collected:

1. Logs: Every user interaction with the ubiquitous services was monitored and stored in log files
2. Video recordings: Two cameras were used to record user interactions from different perspectives. One camera was focused on the screen of the device and the other was focused on the participant. The first camera provided us with information about the users' interaction with the elements of the user interfaces, while the second camera allowed us to analyse more subjective aspects of interaction, such as body language and facial expressions to analyse more subjective aspects like participants' satisfaction. Video recordings also were useful to keep track of the comments of participants while completing the tasks.
3. Notes: interaction-specific aspects that drew the attention of the experimenters were observed and noted down (for instance, problems that occurred during the interaction, level of assistance provided by the tutors, etc.).
4. Short semi-structured interview: a short post-interaction interview focused on getting information about users' satisfaction and opinions on the interfaces, difficulties encountered when accomplishing tasks, etc. The objective was to additional direct feedback from participants.

Results

The video recordings of the interactions were analysed to see whether users had finished the tasks. The task completion rates showed that all participants were able to finish both the pre-defined and the free choice tasks in both services (see Tables 4.5 and 4.6).

The video recordings were also analysed to examine whether or not the adaptations that Egoki applied had been appropriate. For the first group (blind users) it was not observed any particular problem. This suggests that the applied adaptations (text resources, "heading inclusion" and "interface partition") were suitable in this case. When it comes to the second group (participants with cognitive disabilities), it was observed from the video records that they initially paid attention only to the pictures and

	service 1		service 2	
participant	task 1	task2	task 1	task2
P1	93	62	53	45
P2	230	565	188	65

Table 4.5: Task completion times (in seconds) for both services (first user group).

	service 1		service 2	
participant	task 1	task2	task 1	task2
P1	370	375	360	85
P2	325	265	555	160
P3	120	135	110	30
P4	70	60	105	40
P5	260	32	270	75
P6	400	165	175	115
P7	610	240	315	40
P8	140	185	310	75
P9	245	140	60	95

Table 4.6: Task completion times (in seconds) for both services (second user group).

icons, but the associated audio resources seemed to be the most helpful elements, while most of them seemed to ignore textual resources. Therefore, the “info redundancy” adaptation technique played a key role for participants with cognitive disabilities. The “interface partition” adaptation was also of help because it divided the UI into simpler UIs. The drawback was the navigation links required for this adaptation, which seemed to be not so intuitive for some participants at first. Due to the difficulties of participants in focusing their attention, it was important to keep interfaces as simple and clear as possible. Finally, it was noticed that the “task sequence” adaptation technique was not particularly beneficial for participants with cognitive disabilities. While some participants simply did not pay any attention to it, others found it confusing. Although it was intended to inform them about their progression in task completion, five of nine participants tried to press it. They thought that it was an interactive rather than informative element. Therefore, this adaptation technique needs to be analysed and redesigned to be valuable and useful.

Participants commented during the post-interaction interviews that the UIs were very easy to use. Comments from both blind participants confirmed that the provision of textual resources was adequate for participants of the first group (blind users). They also appreciated the "heading inclusion" adaptation technique, as they said it facilitated the interaction with the screen readers. However, they did not particularly like the "interface partition" adaptation technique. Comments of participants of the second group supported the evidence of the suitability of the information redundancy adaptation. Audio messages providing information redundancy were appreciated by the users. Some participants commented that they would have preferred bigger buttons.

Even though all participants accomplished the given tasks, each participant applied different strategies when completing the tasks. This was more obvious in the case of participants with cognitive disabilities. They required a varying amount of support from their tutors depending on their cognitive abilities and the tasks they had to complete. The level of assistance required from the tutors may be related to problematic situations faced by participants. Therefore, it was decided to further study the level of assistance given by the tutors to the participants, with the objective of detecting with a more level of detail the most significant problems encountered by participants. This level of assistance was measured on a four-level scale. This scale is the one commonly used by the tutors of the sheltered workshops of the Gureak Group (where all participants of the second group worked at):

- *Level 3*: when the tutor needs to physically assist the user to perform an action. For example, the tutor places a finger of the user on a specific interaction element on the tablet or it is the tutor himself who performs the action.
- *Level 2*: when the tutor indicates verbally and by gestures how to perform an action. For instance, by indicating with her/his finger the appropriate interaction element on the tablet.
- *Level 1*: when the tutor assists the user with only verbal indications (without gestures) for performing an action.
- *Level 0*: the user performs the action without any assistance from the tutor. However, they may require help for understanding and remembering the tasks.

For this purpose, each task they had to complete was divided into simpler actions and assigned the level of assistance given for each action. Service 1 was divided into 7 actions, while service 2 was broken into 3 actions. For example, the actions that needed to be performed to complete the tasks (select a menu) in service 1 were the following: "select first course" (a1), "go to the second course selection" (a2), "select second course" (a3), "go to the dessert selection" (a4), "select dessert" (a5), "go to the confirmation" (a6) and "confirm/print selection" (a7). The actions required to complete the tasks on service 2 were the following: "select bus line" (a1), "confirm the selection" (a2) and "print the information" (a3). "Selection" actions entail pressing the image of the desired choice in order to select an option, while the "go to" and "confirmation/print" actions involve pressing a link and a button element respectively. Table 4.7 and 4.8 show data related to the level of assistance required for service 1 and service 2 respectively.

The maximum level of assistance for the entire experiment was 2. Nobody required physical assistance for completing the tasks. However, most participants required frequent assistance to remember the objectives of the tasks, due to their difficulties in maintaining attention during the test.

service 1	task 1							task 2						
id	a1	a2	a3	a4	a5	a6	a7	a1	a2	a3	a4	a5	a6	a7
P1	0	2	0	0	0	0	1	2	1	0	1	0	0	2
P2	0	1	0	0	0	0	0	0	0	0	0	0	1	0
P3	0	0	0	0	0	1	1	0	0	0	0	0	0	0
P4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P5	0	0	0	0	0	1	0	0	0	0	0	0	0	0
P6	0	2	0	1	1	0	0	0	0	0	0	0	0	0
P7	0	2	0	0	0	0	2	0	0	0	0	0	0	2
P8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P9	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.7: Level of assistance of participants for individual actions in each task (service 1).

The results indicate that the actions where they needed lower levels of support were those involving the "selection" of options (see Tables 4.7 and 4.8). That is, tapping on the corresponding icon. In contrast, the "confirmation/print" and "go to" actions required a greater level of assistance. These entail activating a button to confirm the selected options (actions a2, a4, a6 in service 1) or activating a link to continue with the next step (action a7 in service 1 and actions a2 and a3 in service 2).

service 2	task 1			task 2		
id	a1	a2	a3	a1	a2	a3
P1	1	1	0	0	0	0
P2	2	2	1	0	0	0
P3	0	0	1	0	0	0
P4	0	0	0	0	0	0
P5	0	0	0	0	0	0
P6	0	0	2	0	0	0
P7	0	2	0	0	0	0
P8	0	1	0	0	0	0
P9	0	0	0	0	0	0

Table 4.8: Level of assistance of participants for individual actions (a) in each task (service 2).

4.3.3 Discussion

First group: blind participants

Results from the accessibility evaluators showed some minor barriers on the UIs for service 1 and no barriers were detected in this case for service 2. In addition, it was observed that all barriers were side effects of applying the adaptation that divided the UI into simpler UIs. Nevertheless, both participants finished the given tasks and did not find any particular problem with the UIs. Comments from participants confirmed that the adaptations related to the inclusion of textual resources and headings were adequate. However, they did not particularly like the division of the UIs into simpler ones. They suggested that having all the content into one UI would increase the efficiency. This could have been influenced by the high computer expertise level of participants, and the fact that the UI was quite simple for providing all the content on a single UI.

In a nutshell, even if evaluators found some minor barriers on the UIs, participants did not have any problem interacting with them. However, for efficiency purposes, they would have preferred to have all the information in one UI rather than having to navigate through different user interfaces. This reflects the complex relationship among accessibility, usability and user experience, which should be further investigated.

Second group: participants with cognitive disabilities

Results from the accessibility evaluators showed some minor and significant barriers on the UIs for both services. As in the case of the first user group, in this case some of the identified barriers were also a consequence of having applied the "interface partition" adaptation. It was also noticed that there were some barriers related to the resources provided for generating the UI, as well as to the information given by the service in real time. In those cases the problem is related to the quality and adequacy of the resources, as Egoki cannot deal with the creation of alternative resources on the fly.

Even if all participants finished the given tasks for both services, problems that users faced during completing the tasks were analysed on the video recordings, with as special attention on the applied adaptations. The "information redundancy" was very helpful, specially the audio resources seemed to reinforce the actions of participants, and this might made them feel less uncertain about the interaction. The "interface partition" adaptation was also of help because it divided the UI into simpler UIs. The drawback was the navigation links required for this adaptation, which seemed to be not so intuitive for the participants at first. Regarding the "task sequence" adaptation it was observed that it did not work as it was intended. One of the reasons could be that information redundancy was only applied to the interactive elements of the UI, so it did not contain any related audio resource. More research is required to redesign the implementation of this adaptation in order to be helpful for the users.

The problems found by participants of group 2 were further analysed by looking into the level of assistance required by each participant. Data show that higher levels of assistance were required in actions related to tasks which required confirming an action or going to a next step on the user interface, in comparison to actions for selecting items. This matches the analysis of the problems with the adaptations, which suggests that interaction elements with more complex actions may require different adaptations in some cases, in order to guide users in the interaction.

4.4 Conclusions

This chapter presented the Egoki system, which is a web-based UI generator that automatically generates user adapted UIs for ubiquitous services. Egoki follows a model-based approach, which based on the information about the abilities of the user, the features of the mobile phone, the adaptations and the formal description of the service, it generates a UI adapted to the needs of users. In summary, it transforms the abstract description of the interface of a service into an operable and functional UI which is adapted to the needs of the user and his/her device. The user, device and adaptation models are implemented by means of an ontology. The reasoning rules specified into the ontology allow the selection of the most suitable adaptations and resource types, for a given user with a specific access device. By means of a combination of XSL transformations and CSS rules, the selected resources and adaptations are applied to generate the adapted UI is automatically.

With a formative purpose and with the aim of identifying a potential list of problems on the automatically generated interfaces, these were evaluated by means of different methods. To this end, the UIs generated for two services (lunch menu selection and bus line information request) for two different user groups (blind users and users with cognitive disabilities) were used as stimuli. The manual evaluation performed by accessibility evaluators identified some potential barriers on the UIs. Most of the potential accessibility barriers were related to the resources provided and applied adaptations. This highlights the key role that the provided resources play in the process of generating the adapted UI. The quality of the automatically generated UIs heavily depends on the variety and suitability of the resources supplied by the service provider. Results obtained from the user testing showed that all participants were able to complete the proposed tasks for both services. In the case of blind users, even if evaluators found some minor barriers on the UIs, participants did not have any problem interacting with them. However, for efficiency purposes, they claimed that they would have preferred to have all the information in one UI rather than having to navigate through different user interfaces (as a consequence of having applied the "interface partition" adaptation). This reflects the complex relationship among accessibility, usability and user experience, which should be further investigated. In the case of the users with cognitive disabilities, while some adaptations applied were found to be useful, others need to be redesigned in order to be more intuitive. Specially adaptations that correspond to interactive elements that require more complex actions.

The results of the performed evaluation suggest that the approach that Egoki follows for providing automatically generated adapted user interfaces for interacting with ubiquitous services is feasible (as the generated UIs were fully operable), but the user interfaces can benefit from some additional refinements.

Chapter 5

Web accessibility and User Experience (UX)

While some authors claim that conformance to guidelines can produce more accessible, usable or mobile-friendly websites, others say that there is no evidence to support such a statement. Guidelines can be understood as a basic step towards obtaining a better web experience although it may not be sufficient on its own. Accessible and adapted user interfaces should provide users not only with access to all the resources contained on the user interface, but also with an enhanced user experience. There is no point in providing users with accessible or adapted user interfaces, if that does not have a positive impact on their user experience. Nevertheless, the relationship between web accessibility and user experience has not been completely explained yet. This chapter broadly explores this topic, by examining the user experience in relation to a comprehensive perspective of web accessibility: subjective perceptions and objective assessments.

5.1 Introduction

The previous chapter described the Egoki system and the adapted user interfaces that were automatically generated by the system for different services. According to the evaluation conducted by experts, the generated adapted user interfaces contained some potential accessibility barriers. Most of the potential accessibility barriers identified by the experts were caused by the used resources. This poses interesting questions with regard to the Web-based user interfaces generated by Egoki. For instance, the important role played by the resources, the evaluation methods used for evaluating their accessibility, and the user experience of participants. In this chapter the focus is on the last issue. Can user interfaces with potential accessibility problems provide users with a positive user experience?

When it comes to websites, evidence suggests that compliance to accessibility standards (WCAG 1.0, 2.0 [24, 29]) does not necessarily guarantee a satisfying user experience. Studies that corroborate such evidence state that guidelines compliant websites can be inaccessible for specific users in specific situations. The other way around also applies: non-compliant websites do not necessarily have to pose a challenge to users. For instance, Petrie et al. [89] conducted a user study with 51 participants with disabilities, where the authors observed, identified and classified the difficulties that users encountered. They found that 45% of the observed problems were not related to any violation of WCAG 1.0 checkpoints [29]. The second version of guidelines, namely WCAG 2.0 [24] was released to address the weaknesses exhibited by the previous versions and to cater for the technological updates that occurred hitherto. An empirical study [92] was conducted about the problems identified by 32 screen reader users on the Web. Results revealed that only 50.4% of the problems encountered by participants were covered by WCAG 2.0 success criteria (henceforth SC). Consistent coverage figures —measured in terms of the percentage of actual problems addressed by guidelines— were reported [97]. Among those problems not covered by the SC, the 13.5% of all user problems detected were related to unmet expectations in terms of unexpected content [92].

Even if guidelines are an invaluable starting point for building accessible sites, the above-mentioned findings indicate that there is a need to explore complementary ways of building accessible websites beyond conformance to guidelines. In this regard, understanding how users experience and perceive web accessibility is vital to bridge this gap. The success of a website often goes beyond its objective properties an depends on how the end-users perceive it. Since behaviour is always accompanied by subjective experience, in this chapter the interaction with websites is explored in a more holistic way.

UX and web accessibility

While researchers have investigated for years how to develop more accessible web pages for users with disabilities, it is unclear the extent to which compliance with accessibility guidelines improves the user experience. So far, there are very few research works in the literature relating UX dimensions and web accessibility. One exception is an empirical study [80] that reports evidence on the relationship between aesthetic features of websites and accessibility. In this case web accessibility was assessed by the Barrier Walkthrough [16] method focusing on people with visual impairments. Results showed that only one dimension of aesthetics (*visually clean*) was significantly related with web accessibility. That is, they found that web pages judged on the classical aesthetics dimension as being visually clean showed significant correlations with accessibility.

This suggests that a more comprehensive understanding of the relationship between web accessibility and UX is required. In addition, the experiential and subjective quality of web accessibility remains barely unexplored. In this chapter two research questions are explored: 1) How do blind users perceive and experience web accessibility? (Q1); and 2) Is there any relationship between web accessibility and UX? (Q2).

5.2 Method

This chapter examines the relationship between the user experience and web accessibility from a broad perspective. This involved studying web accessibility from a subjective and a more objective perspective. Therefore, both qualitative and quantitative research methods were used in order to gain a holistic understanding of the nature of the relationship.

5.2.1 Participants

Eleven legally blind participants —four female participants—, who were representative of the user group being studied [103], were recruited in partnership with the National Organisation of Spanish Blind People (ONCE)[1].

[1] `http://www.once.es/new/otras-webs/english`

The median age of participants was 43 years, with a range of 21–64 years. Table 5.1 shows demographic data as well as the characterisation of user expertise in two ways: self-reported and observed skills (columns 6 and 7 respectively). The former was collected by asking participants to rate their web expertise on a four-item scale: expert, advanced, intermediate and beginner. In order to avoid the bias of self-judgements web expertise was also assessed from the perspective of an external observer. This last indicator was computed using observations of the experimenter and the reports of the instructor, who trained the participants for improving their computer skills at the local delegation of ONCE. Specifically, the main focus was on the strategies employed and the confidence shown when carrying out the tasks. As shown in Table 5.1, self-rated and observed skills did not always match. This is in line with the conclusions of a study conducted by van der Geest et al. [113], which shows that self-rated Internet competence of visually impaired users is not always related to their actual performance on common Internet tasks.

id	gender	age	familiarity with the Web	frequency of Web use	self-reported expertise	observed expertise
P01	F	29	>7 years	daily	advanced	expert
P02	F	29	>7 years	daily	advanced	expert
P03	M	39	>7 years	daily	advanced	advanced
P04	M	54	4-6 years	daily	intermediate	intermediate
P05	M	43	1-3 years	weekly	beginner	intermediate
P06	M	21	1-3 years	weekly	beginner	beginner
P07	M	64	>7 years	daily	intermediate	advanced
P08	M	58	>7 years	daily	intermediate	intermediate
P09	F	54	4-6 years	daily	intermediate	advanced
P10	M	64	4-6 years	daily	beginner	intermediate
P11	F	42	>7 years	weekly	intermediate	beginner

Table 5.1: Participants' demographic data and characterisation of their expertise on the Web.

5.2.2 Apparatus

All participants were legally blind and utilised screen readers to navigate on the Web: ten participants were Jaws users (version 10, except P01 and P03 who used version 12) on Internet Explorer/Windows (XP and Win 7), while just one participant (P02) was a VoiceOver user on Safari over MacOS. The first three participants were observed in the research facility of the HCI laboratory at the School of Computer Science of the University of the Basque Country, and participants brought their own laptop. The remaining sessions took place in a room at the ONCE delegation in Donostia-San

Sebastián, where the other eight participants used the same laptop and keyboard, which were provided by the ONCE.

5.2.3 Stimuli

In order to let the subjective dimensions emerge, local participants were recruited and websites of restaurants, that were popular and well-known in the area where they lived, had been selected. The focus was on only one type of website, so that analogous tasks across different stimuli could be established, and also to minimise confounding factors related to the type of stimuli. According to the taxonomy proposed by de Marsico et al. [33], the restaurant websites selected as stimuli fall onto the categories of *commercial* sites, are targeted to a *general* audience and exhibit an *informative–seductive* communication style.

When websites were sampled, as the objective was to study how users experienced websites with different accessibility issues, the main selection criteria was the accessibility level of the websites. Unfortunately none of the local restaurant websites was found to be fully compliant with WCAG 2.0 level AA. Also, it must be noted that some websites were discarded due to the severe accessibility problems they contained in the homepage. Another selection criteria was about branding issues. W1 and W3 (see Figures 5.1 and 5.3) represent internationally well-known restaurants with an innovative character. Their culinary style is based on creativity, investigation and experimentation. Their 'author's cuisine' has been recognised worldwide by the award of Michelin stars. In contrast, the other two restaurants (W2 and W4), even if they are quite popular in Donostia-San Sebastián, their style is based on traditional Basque cuisine. As it can be observed in Figures 5.2 and 5.4, the visual design of the websites is aligned with the style of the restaurant: the internationally renowned restaurants (those having an innovative and avant-garde style: W1 and W3) use a reduced colour palette, have had their typographies designed and contain high-quality close-up pictures. On the other hand, the design of the traditional restaurants is less ambitious.

These websites had been chosen by following this selection process: first, 25 websites of local restaurants were listed; then their homepages were evaluated using four automated web accessibility evaluation tools: AChecker [40], EvalAccess [3], TAW [2] and WAVE[3]. Based on the automated tests of

[2] `http://www.tawdis.net`

[3] `http://wave.webaim.org/`

the aforementioned tools websites were classified in four groups: very accessible, accessible, not so accessible, poorly accessible. Within each group, the selection was narrowed down by evaluating again the homepage and two more web pages using the WAQM metric [119]. Then the four groups were merged into two (highly accessible and poorly accessible). Within each group, websites were classified based on branding issues, considering the style of the restaurant: traditional and innovative. After that, an expert evaluation was performed where the Barrier Walkthrough (BW) method [16] was applied. Based on the results, the two most and least accessible websites were selected for each type of restaurant (traditional and innovative). Once the four websites were finally selected (see Figures 5.1, 5.2, 5.3 and 5.4), they were evaluated according to the WCAG 2.0 AA conformance level. Both, VoiceOver and Jaws screen readers were used during the manual web accessibility evaluations.

In general, W1 and W2 present higher accessibility levels than W3 and W4. Their homepages satisfy 73%, 69%, 52% and 36% of the SC for the AA level of WCAG 2.0 respectively. It must be noted that W1 is the accessible version of the restaurant's website (although participants were not told about that detail). The most severe accessibility issue of W3 is that the navigation menu consists of seven images, all with the same 'alt' text, which was the word *image*. In W4, the main accessibility problem is related to Flash based dynamic content that cannot be accessed by the screen reader. More detailed information on the results from the web accessibility evaluations of the websites used as stimuli can be found in the following URL[4].

Figure 5.1: Screenshot of the homepage of the W1 website.

[4] `http://sipt07.si.ehu.es/amaia/stimuli`

Figure 5.2: Screenshot of the homepage of the W2 website.

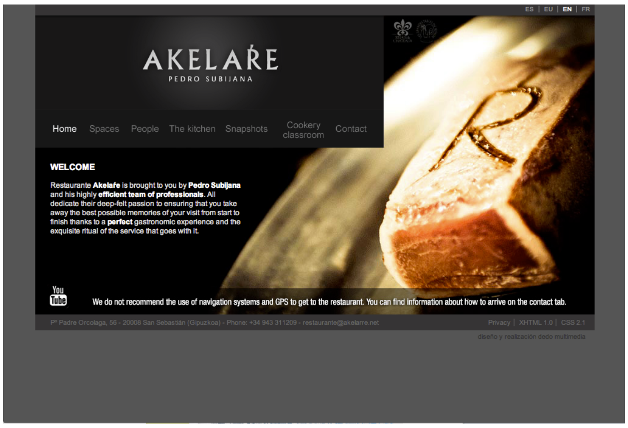

Figure 5.3: Screenshot of the homepage of the W3 website.

Figure 5.4: Screenshot of the homepage of the W4 website.

5.2.4 Procedure

Each session was conducted with one participant at a time. Once the participants were informed about the objectives of the study and the procedure of the session, they signed the consent form. In order to obtain non-biased answers, and make participants feel free to respond as honestly as possible, it was highlighted that there was no relationship nor conflict of interest with the websites. It was also made it clear that there were no right or wrong answers by emphasising that the interest was in their insights and personal opinions. Participants were explained that they were playing the role of testers rather than being the tested subjects. Then, demographic data was collected and participants were enquired about their expertise and familiarity with information technology. After that, participants were interviewed about their previous experiences and expectations regarding restaurant websites. Once the interview had finished, they could start to navigate the first website. After the navigation with each website, by means of questionnaires and semi-structured interviews, information about their browsing experience was collected. This information was diverse and encompassed their perceptions about website aspects, the problems they encountered, the accessibility barriers found and the affective considerations evoked by the websites. Each session, was video and audio recorded to enable subsequent analysis. At the end of the session each participant was rewarded with a USB memory stick for taking part.

5.2.5 Tasks

Each participant was asked to try to complete three tasks on each website. These tasks were the same for each website:

- freely navigate on the website, in order to become familiar with it;
- find information about the gastronomic offer;
- find the means offered by the website to make a booking.

A learning effect was prevented from happening because each website structured its content in a different manner. However, in order to minimise order effects, the order in which websites were presented was counterbalanced. The idea was to let the users explore the website through tasks which were related to the typical expectations regarding restaurant websites. Hence, the tasks were deliberately not very specific and tried to trigger real world situations, where users have an informational goal in mind but explicit directions to accomplish are absent. Participants were told that the time estimated for each task was between 5-10 minutes but it was highlighted that they could spend longer time if they wanted, or even shorter time if they finished or they had lost their interest.

5.2.6 Data collection

As previously stated, two models (the one from Hassenzahl [48] and the CUE-Model [111]) were studied as reference frameworks. Analyzing both models it was found that they hold many similarities: both represent UX based on instrumental and non-instrumental quality perceptions (so-called pragmatic and hedonic qualities in the first model); which result in emotional reactions of users. In addition, both models separate the perception of attributes of an interactive product from the evaluation of it. As a consequence of experiencing the interactive product, the user is able to evaluate and create an overall judgement of it. Table 5.2 summarises the similarities found between both models.

UX model [48]	CUE-model [111]
situation	user characteristics, task/context, interaction characteristics
product features	system properties
pragmatic attributes	perception of instrumental qualities
hedonic attributes	perception of non-instrumental qualities
pleasure and satisfaction	emotional reactions
appeal (beauty and goodness)	appraisal of the system
consequences	both (emotional reactions and appraisal of the system)

Table 5.2: Similarities found in both models of user experience.

In order to choose the data collection methods, different aspects had to be taken into consideration. As the study followed a within subject design, that implied that participants would interact with four websites with the corresponding procedure to collect their insights for each website. Consequently, the data collection instruments should not be lengthy and tedious in order to avoid prolonged testing sessions which may cause users get exhausted. They should also be consistent in terms of the scales they used for assessing each dimension of UX to avoid users get confused with them. Moreover, they should allow both, qualitative and quantitative data collection, and a wide overview of UX (rather than focusing only on one specific dimension) in order to gather the most comprehensive information as possible about UX. With this preconditions in mind, and considering that the UX model proposed by Hassenzahl [48] already had a measurement instrument known as Attracdiff 2 [49], this was the first option as an instrument to capture the UX of participants. Attracdiff 2 questionnaire [49] (see Table

5.3) consists of a set of 23 word pairs reflecting opposite adjectives. These can be rated on a 7-point scale to assess perceptions of users about an interactive artefact on pragmatic quality (PQ) and hedonic quality (HQ) dimensions, also including judgements on beauty and goodness. PQ refers to the usability of the artefact, and focuses on task-related aspects. In contrast, HQ refers to more subjective quality dimensions in terms of stimulation, identity communication (identification), and valued memories (evocation) [48]. Even if other existing instruments were also considered (see the first technical report in the Appendix A section) as alternative instruments to those in Attracdiff 2 for assessing different UX dimensions, only an additional method was finally included with regard to emotional reactions.

With the intention to complete the data collection about the UX, and specifically the emotional reactions of participants, the emotion word prompt list (EWPL) [90] was also included into the data collection instruments. The main reason for this was to broaden the data to be collected beyond the Attracdiff 2 questionnaire with regard to the emotional reactions. The EWPL consists of 11 emotional words (see Table 5.4) that can be rated through 7-point Likert items (e.g. from 1, low intensity, to 7, high intensity). A valuable aspect of this instrument was that it was designed for websites, is that it offers the possibility of using it as a quantitative as well as a qualitative method.

Both questionnaires (Attracdiff 2 and EWPL) had been translated into Spanish in order to use them in this study. Even if translation of the items was carefully done, the validity of the employed scales was not tested. Considering the exploratory nature of the study, it was out of the scope of this research goal to demonstrate the validity of the translated assessment instruments.

No instrument was found to assess the perception of web accessibility, therefore, the example of the other instruments selected for this study was followed. Information about web accessibility perceptions of participants was obtained by asking participants to rate the accessibility of each website in a 7-point Likert-type question, from 1 (very inaccessible) to 7 (very accessible).

A self developed semi-structured interview was also employed aimed at gathering deeper insights on the aspects collected by means of the questionnaires. For instance the moment and the reasons for their emotional reactions, the problems they encountered while navigating, and the positive and the negative aspects of the websites.

Each session was video and audio recorded, to keep track of interactions with websites and interviews respectively, and enable subsequent analysis.

scale	anchors
hedonic quality-identification (HQI)	
HQI_1	isolating–integrating
HQI_2	amateurish–professional
HQI_3	gaudy–classy
HQI_4	cheap–valuable
HQI_5	noninclusive–inclusive
HQI_6	takes me distant from people–brings me closer to people
HQI_7	unpresentable–presentable
hedonic quality-stimulation (HQS)	
HQS_1	typical–original
HQS_2	standard–creative
HQS_3	cautious–corageous
HQS_4	conservative–innovative
HQS_5	lame–exciting
HQS_6	easy–challenging
HQS_7	commonplace–new
pragmatic quality (PQ)	
PQ_1	technical–human
PQ_2	complicated–simple
PQ_3	impractical–practical
PQ_4	cumbersome–direct
PQ_5	unpredictable–predictable
PQ_6	confusing–clear
PQ_7	unruly–manageable
evaluational constructs	
beauty	ugly–beautiful
goodness	bad–good

Table 5.3: Bipolar verbal anchors for *hedonic* and *pragmatic quality*, *beauty*, and *goodness* [49]

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5.3 Q1: How do users experience web accessibility?

5.3.1 Data analysis

The unexplored and subjective nature of the experienced accessibility calls for a preliminary qualitative approach [5] (over the semi-structured interviews), that will inform subsequent stages of this research. The six phases of the thematic analysis [20] were followed:

- Familiarising with the data;
- Generating initial codes;
- Searching for themes;
- Reviewing themes;

emotion word	valence
annoyed	negative
bored	negative
confident	positive
confused	negative
disappointed	negative
frustrated	negative
happy	positive
interested	positive
hopeful	positive
pleased	positive
unsure	negative

Table 5.4: Emotion word prompt list, EWPL [90].

- Defining and naming themes;
- Producing the report.

An open coding phase was performed in order to identify the emerging themes in the data. Transcripts were printed on paper and by using highlighters of different colours potential themes were identified. In order to review and validate the identified themes, all transcripts were analysed again using NVivo 10, a qualitative data analysis software. To ensure the reliability of the coding scheme, an external coder was asked to review the transcripts and use the initial coding scheme to code the data. Cohen's Kappa statistic was computed to measure the average level of agreement between both coders. A coefficient of 0.86 was obtained, which indicates a substantial level of agreement. Even if the agreement was quite high, the results were shared and the discrepancies were discussed and resolved. This exercise led to some changes in terms of adding and deleting some instances on the final coding scheme.

The following sections present the themes and sub-themes found with regard to the experiential aspects that emerged from the interaction of participants with the websites[5].

5.3.2 General expectations (10)

An expectation is defined as anything expected by the participant, no matter if it is met or not. That is, expectations are any assumption that may

[5]The number between parentheses indicates the number of users who reported each sub-theme.

or may not be real. The general expectations participants had with regard to the restaurant websites, were built up on to previous experiences: either real (physically at restaurants) or on the Web (with similar websites). Not surprisingly, most participants expected to find information about the gastronomic offer, prices, contact, location, regular timetable or bookings.

Experiences at restaurants Participants relied on past experiences at restaurants to express what they expected from these websites. Beyond specific content, three participants wanted restaurant websites to provide them with enough and useful information to control the situation when they were physically at the restaurant. As a consequence of having experienced uncomfortable situations in the past, they reported that they usually try to avoid these situations by visiting the website before going to the restaurant. This provides them with useful information to figure out what they can find in the restaurant, and also increases their sense of autonomy and security. This strategy is a way to take precaution to avoid potential uncomfortable situations, and thus, it can facilitate the real experience at the restaurant: *"There are many times that you have such a long menu, which is a pain, because the waiters don't even ask you later. They say 'we have this, this and this', when the menu is about 30 dishes! . . . but they decide for you what you don't want . . . Of course, if someone has to read the menu you can spend 15 minutes there reading the menu. I understand that. Well, in order to avoid this I check the menu on the Web"* (P02).

Experiences on the Web In addition to real experiences related to restaurants, past web experiences with other restaurant websites may also contribute to the creation of expectations. For example, the two participants who habitually visited restaurant websites did not expect them to be accessible as they often came up with many inaccessible websites: *"They are very inaccessible, I tell you! Horrible, they are horrible, besides many of them have Flash, and now with HTML5 Flash is not needed . . . Online reservations are oof! . . . a nightmare . . . a nightmare and you end up calling them* [on the phone]" (P02).

5.3.3 Website specific expectations

General expectations refer to any restaurant website, while specific expectations are related to what participants expected from a particular website. In comparison to general expectations, these are more related to the aspects of a particular website such as content and functionality. While participants navigated a website, the expectations they had with regard to its content or functionality were not always met.

Content-related expectations

Content found where not expected (4) Encountering content in unexpected locations was not a major problem provided that the content was a relevant piece of information to complete the given task. Some even seem to be surprised of having found it unexpectedly: e.g. the telephone number was very handy at the beginning of the homepage in W2 "*We already have a task done!* [Laughs]" (P09-W2). However, if they found something they did not want it did not match their mental model participants got confused: "*Yes, before the first link, or the ... well, there was 'History', the link was 'Restaurant', well I don't know what it is doing there*" (P03-W4).

Content not found where expected (10) Sometimes participants did not find the content they wanted on a website. Either because of difficulties with the website, the assistive technology, because their search strategy was not effective or because the content were looking for was not in the website. The majority of the comments from participants were related to information about the given tasks, especially about the gastronomic offer: "*The menu was what I wanted to see ... the menu and the prices*" (P04-W1) and "*It does not have no menu nor anything. Because if you go to a website I could not care less about the history, what I want to know is what to eat*" (P06-W3).

Content not found as expected (11) This happened when the content was in a different form than expected by the participant. For instance, P09 thought that the menu would come in a document such as a PDF, or a list of dishes on the same page. However, in the W2 website, information about the gastronomic offer was conveyed through links. In fact, participants had to navigate through different pages that were located at different depths in order to get the information. "*The menu, I expected to see a document all together ... and there was no menu as such, it was like a bunch of links*" (P09-W2).

Not accessed content (4) Expectations sometimes go beyond the content that participants visited. Sometimes only by the link text, they made assumptions about the content beyond the link, even without exploring the web page. For instance, one participant imagined that the video on the W3 website was a welcoming video: "*There was also a welcoming written text, with an attachment or a link to Youtube, well I understand it's for welcoming, because it was next to the written text*" (P03-W3).

Content labelled as 'accessible' (5) It was surprising to observe how the 'accessible' keyword aroused the interest of the participants. It can also generate expectations regarding the content to which it refers. There was a video on the W2 homepage, which had a link next to it that said 'accessible version of the video'. None of the participants played the video neither visited the link of the accessible version of the video but later on the interview four participants mentioned the detail of the accessible video: "*I wanted to look at it because it said 'accessible video' ... I forgot to check it out but I wanted to look at it, huh? For me when they put accessible makes me want to try it, right? Then, sometimes you say 'to hell with this accessibility!' Isn't that so? But anyhow, it denotes a level of interest; the designer of the Web may have done it thinking about something or someone ... Well, that is appreciated*" (P10-W2).

In addition, as previously mentioned, W1 website was in this case the accessible version of the website. So, it contained a link with the 'normal version' text. As soon as P09 realised that she was navigating on the accessible version of the website she said: "*Wow! ...finding an adapted version, even if we say it does not influence our mood, we are already applauding!*" (P09-W1). Nevertheless, she did not experienced W1 to be accessible, and after the navigation she said: "*As I was browsing I was feeling as if I lacked resources, because I figured that if the version was accessible, it'd be for some reason, and if I wasn't finding information, I was thinking: others* [referring to participants] *would have found it, because it's accessible, and I look silly because I'm not able to find the information*" (P09-W1). In addition, she reported that it is frustrating when something is claimed to be accessible apparently, but finally it turns out that is not: "*that bothers me very much ... it's bothering when a company claims to be as such ... then you get disappointed ... it feels like being cheated*" (P09-W1).

Beyond the specific case of W1, different positions and opinions were observed with regard to the accessible or the normal version of a website. Some expert participants said that they usually access the normal version of the websites, even when visiting it for the first time. "*I always try the other* [referring to the "normal" version], *but because I want to and I am weird*" (P02). In contrast, most of the other participants (non-experts) stated that they usually visit the accessible one if it was available, mainly because they expected to be the most convenient or easiest way. "*of course I will always go to the accessible one, I always hit the button to make it more accessible for me*

... I don't know in what way 'accessibilises' it for me, because I do not know much about computers" (P05).

P07 reported that with one particular online newspaper he used to access the text only version, until he realised that it was less complete than the original one. This stopped him from visiting alternative versions of websites and hitherto he sticks to original versions. Another participant said that he usually visits the accessible version of the website, especially if he is browsing in an operative mode, rather than in a more exploratory mode: *"yes I go there* [to the alternative version], *especially if you're in a working attitude, I mean that if you're going to do something in particular"* (P10).

Two different positions on alternative website versions were observed. Some participants thought that it is not a good approach, and would prefer the website to be accessible without the need of having an alternate version: *"I always try the other, and I do not find that page* [the accessible version] *accessible ... I don't want to be separated ... aren't we going towards the integration?"* (P02). In contrast, others feel good about having an accessible version, as long as it is conveniently handy. *"I don't go looking for it ... if I knew that all the websites have an accessible feature, I assure you that is the first place I would go ... "* (P08).

Functionality-related expectations

In addition to the content, expectations are also related to the functionality of the website. In this context functionality refers to processes and achievable outcomes.

Expected functionality not present (10) This happened when a website did not provide participants with the expected functionality. For example, in W4 a participant expected that by activating a button he could make a booking: *"I wanted to press the button and the reserve by email would show up"* (P05-W4).

Functionality does not work as expected (9) This refer to situations where website elements do not work as expected by participants. For instance, links that unexpectedly opened a new window or a new application misled the participants: *"I don't know where it has taken me to, to a very strange place, and then you restored it. Well, that could be also as a sign of something that ... I cannot tell because I don't know where it took me ... but I was thinking 'well,* *let's see if it takes me to a section for bookings', that's why I entered, but it didn't happen"* (P10-W3).

5.3.4 Preconceptions (9)

Participants' preconceived ideas regarding the restaurant represented by the website (e.g. branding issues) also affected expectations on the website which can later impact on their perception of the accessibility of the website. Some participants were bothered —and even swore— by the experienced lack of accessibility of the W3 website. The anger was fuelled by the fact that W3 is an internationally well-known restaurant: *"If it's so luxurious, they should bother to put it right but they don't care, because as they have lots of money, they would say 'people who know me they know where I am' . . . Restaurants will say: 'ahh I'm already rich, I don't care if they* [referring to blind customers] *don't come*" (P06-W3).

Surprisingly, two of the restaurants of the websites (W1 and W3) used in this study, had previously carried out initiatives to promote accessibility and get closer to people with visual impairments: the *accessible pintxo*[6] initiative, and offering the menu in Braille, respectively. In the case of the W1 restaurant, the pintxo was specially created for blind people with the aim that they could enjoy this type of 'social snack', which is very traditional in the area where participants lived. The objective of the initiative was to raise awareness on the difficulties that blind people have to face in their daily routines. These findings suggest that being aware of these initiatives carried out by restaurants in order to promote accessibility, can influence expectations regarding the accessibility of the website. *"Surprised, pleasantly surprised, I did not expect . . . I knew that the restaurant had done some pro-accessibility things, not on the Web but in general. And that they have been doing some things with the ONCE and such, but I did not think . . . yes the accessible pintxo, silly things in my opinion but . . . well, maybe that served them to realise that an accessible site is needed*" (P02-W1). P09 knew that those two restaurants had their menus in Braille. Consequently she assumed that their respective websites would be accessible: *"maybe you're not going to eat at the Arzak or Akelarre restaurant* [two well-known upmarket local restaurants, the latter is the restaurant of W3], *but I guess their website is accessible because they have the menu in Braille . . . even if it's never updated!*" (P09).

[6] A *pintxo* is the Basque equivalent of a Spanish tapa: a miniature dish you can eat while standing up by the bar.

5.3.5 Evoked memories (6)

The memories of participants from their past experiences emerged while carrying out their tasks. These memories were triggered by the recall of the experience of having been at that restaurant, or by content of the website that reminded participants of an emotional bond to someone or something: "*I was happy, because apart from having been at Mugaritz* [the restaurant corresponding to W1], *Mugaritz is located in an area to which I have much affection*" (P05-W1). P09 remembered that time when she went to the W4 restaurant with her father. She remembered fondly as an endearing and satisfying experience and expected the web experience corresponded to the real one: "*I felt happy because I like playing with the pages, and because I was remembering when I had been in* [the restaurant of W4] *with my father . . . I've been once or twice. In both cases I had dinner with very few people in the dinning room . . . A little disappointed for that reason, because for such a restaurant of quality, and especially for the intimate and satisfying eating experience I've had, nevertheless it's like the website did not match up to my experience*" (P09).

P10 commented that he recalled that his parents used to go to have dinner at the restaurant of W4 on the festivities of Donostia-San Sebastián: "*I also have remembered that my father and my mother used to go there on the festivities. They used to come to Donostia and then go to this restaurant to have dinner*" (P10-W4). Checking the wine list on W2, P10 noticed that there was a selection of wines from the Canary Islands, which caught his attention. He said that he wanted to see if there was a special wine called Malvasia: "*I have seen the types of wines it reminded my of the Canary Islands, because there is a typical wine that is the Malvasia . . . I entered Canary Islands link*" (P10-W2).

5.3.6 Uncertainty

Confusion generated by the website (11)

It was observed that participants' non-met expectations are often related to certain level of uncertainty and confusion. It is not only about expectations that have not been met, but the associated feeling of uncertainty about why they were not fulfilled. For instance, most participants expected to find a menu on the websites. Even if W1 contained information about gastronomic offer, it did not contain a menu as such, however participants reacted differently: one of the expert participants was aware that the page did not contain it. "*It has one fault, which is the menu, I want a menu on the page. Yes, it tells me a few starters, a few seconds and such, and that's fine, but the* *extended menu*" (P02-W1). In contrast, some non-expert participants did not find the expected menu and were not sure if it was because of 'their fault' or due to issues with the website. "*the thing is that I have not been able to find, the main goal I have not achieved, eh? then, probably other blind colleagues would have found it, because I'm sure that the average of the technical resources is higher than mine*" (P10-W1).

When participants were confused about whether it was because of something related to the website, the screen reader, or due to they had done something wrong. This uncertainty about not knowing what happened and why can affect the perceived web accessibility and UX. In the W3, P05 accessed the Youtube link thinking that he would probably find information on the menu: "*The thing is that I don't know if there was something else . . . clearly I'm not sure that I could reach everywhere . . . that's why I got into Youtube, because there they might tell you*" (P05-W3). "*I don't know, I got lost with the buttons . . . the thing is that I don't know why buttons exist ... I don't have the concepts clear about the difference between a link and a button*" (P10-W4). The number of comments about how confusing web content was completely unbalanced between the most accessible websites (W1, W2 got 13 comments) and the least accessible ones (W3, W4), which got 39 comments. This supports the relationship between accessibility problems and confusing situations [120].

Confusion related to confidence and expertise (7)

The uncertainty of participants was closely related to their perception of their own skills and their confidence. Intermediate and advanced participants exhibited a lack of confidence and blamed on themselves when encountering problems : "*I see that I am very clumsy. If I had a better opinion about myself, I'll probably be more critical with the web accessibility*" (P10-W1). Those participants at both ends of the spectrum (i.e. beginners and experts) attributed the cause of problems to the website or the screen reader rather than to themselves.

5.3.7 Experienced web accessibility

After completing the tasks, accessibility ratings were collected and participants were enquired about the problems they encountered. Table 5.5 shows the accessibility ratings given by participants on a 7-item Likert-scale where 1 indicated 'very inaccessible' and 7 'very accessible'. The median values suggest that participants perceived W1, W2 and W4 to be similarly accessible. However, a smaller standard deviation in W2 and W3 indicates a broader consensus among participants than in the case of W1 and W4. In the case of the latter two, although opinions varied, most participants considered them to be accessible.

website	AA compliance	median	mode	SD
W1	73%	6	7	1.95
W2	69%	6	6	1.42
W3	52%	2	1	1.62
W4	36%	6	6	1.95

Table 5.5: Participants' experienced web accessibility ratings (1: very inaccessible–7: very accessible) for each website.

Website 1 (W1) P06 withdrew from the website as JAWS was getting blocked: "*sometimes JAWS gets stuck and doesn't respond*" (P06). P09 and P10 were not very confident talking about accessibility barriers: they both agreed on the large amount of visual information that W1 contained. Even if images had an alternative text, the fact that the text was not meaningful for them was perceived as a barrier: "*I may have preferred a description of the person, some biographical data, or a phrase, or how the person entitles his dishes . . . [but] when I hear 'the portrait of our people' [as alternative text] . . . this leaves me overwhelmed*" (P10).

Participants also complained about not being able to find the menu even if this website did not contain a menu as such: "*I haven't found any practical information, not even the menu . . . you cannot access the content. Even if the sections are marked up, you click on those links and once you are in a section there is nothing there . . . the most frustrating thing is going to a restaurant and not knowing what to eat*" (P09).

Website 2 (W2) Only P01 rated it as non-accessible, which was mainly due to network connection issues. She said the page seemed to be accessible, but because of a problem when loading web pages she could not give it a better score: "*I think it's accessible, but I couldn't go beyond the links*" (P01).

Website 3 (W3) All participants except P11, who said the web page was very simple and lacked major difficulties, perceived W3 to be non-accessible. The fact that P11 did not navigate beyond the homepage may explain this outlying perception. Most participants mentioned that the navigation menu of the website was completely inaccessible because each menu item was a graphic link with the same alternative text (i.e. *image*). Consequently many of them did not even try to click on those links and their navigation was exclusive to the homepage.

The mental map of some participants was mismatched to the information architecture of W3. P03, who was able to distinguish between the structure from the content of the website, was ambivalent about the accessibility/non-accessibility of the website and did not lean towards any end of the scale. According to P03, W3 had a very simple structure, which made navigation easy. However, the scarcity of content was considered a problem: "*when it comes to move, you can move without any problem, the problem is related to the information in those links*" (P03).

Website 4 (W4) Most participants thought W4 was quite accessible while two participants (P01 and P07) were ambivalent about it. It was observed that the majority of participants were not aware about the presence of non-accessible dynamic content and therefore did not perceive the accessibility barriers. Nevertheless they were suspicious about something going on: "*unless I missed something to browse . . . there wasn't anything or I was not able to seek . . . I wonder if there was a longer menu*" (P09). In line with this, P10 was not sure whether they were missing some content. Both P09 and P10 were disappointed and regretted their ratings when they were told that there was actually more content: "*this devalues the accessibility score I gave . . . it's like there is a walk adapted for people with disabilities (i.e. like a safe path) and there is a hole in the middle, and I walk with my guide dog and step near the edge of the hole. I do not fall over but it could have happened*" (P10).

In some cases that participants experienced a website as accessible, comments about possibly visiting again the website were found. In some cases participants commented their willingness to go to the restaurant: "*I would love to go to the restaurant*" (P05-W1). In contrast, in other cases when a website was not perceived to be accessible, some participants expressed their disappointment in terms of not having the intention to return to the website, neither to visit the restaurant: "*if their page is not accessible, I'm not interested in the restaurant, I'd rather go to the neighbouring restaurant where I'm treated better*" (P06-W3).

5.4 Q2: The interplay between web accessibility and user experience

5.4.1 Data analysis

Data collected by means of the assessment instruments were statistically analysed to check the relationship between the UX of the participants (collected through the questionnaires) and the accessibility of the websites (obtained from the results of the accessibility evaluations of the websites). Two correlation studies were performed to analyse the correlations among: 1) UX dimensions and perceived web accessibility; and 2) UX dimensions and accessibility indicators. The statistical software used was R[7]. In addition, data from the interviews were analysed in order to better understand the importance of the identified relationships and the reasons why they emerged.

5.4.2 The relationship between UX and perceived web accessibility

Kendall's Tau (τ) correlation coefficient test for non-parametric measures of bivariate relationships was used to report effect sizes.

As shown in Table 5.6, most of the correlations (all except 7, 28/35) between PWA and UX dimensions are statistically significant [N=44 (11 participants x 4 websites), $p < 0.001$]. Strong significant ($p < 0.001$) correlations were found between PWA and: Six dimensions of the hedonic quality-identification (inclusive, presentable, brings me closer to people, professional, integrating, valuable), one dimension of the hedonic quality- stimulation (creative), five dimensions of the pragmatic quality (practical, manageable, clear, direct, simple), goodness, appeal, happy, pleased, interested, disappointed, frustrated and annoyed.

Significant and moderate correlations were also found between PWA and: two dimensions of pragmatic quality (predictable, integrating), one dimension of hedonic quality-identification (classy), three dimensions of hedonic quality-stimulation (exciting, new, original), beauty, hopeful, confused and bored.

[7] http://www.r-project.org/

	Kendall's Tau (τ)	p-value
HQI_1 isolating–integrating	0.63	0.000
HQI_2 amateurish–professional	0.64	0.000
HQI_3 gaudy–classy	0.44	0.000
HQI_4 cheap–valuable	0.62	0.000
HQI_5 noninclusive–inclusive	0.68	0.000
HQI_6 takes me distant from people–brings me closer to people	0.66	0.000
HQI_7 unpresentable–presentable	0.67	0.000
HQS_1 typical–original	0.43	0.000
HQS_2 standard–creative	0.55	0.000
HQS_3 cautious–corageous	0.18	0.133
HQS_4 conservative–innovative	0.29	0.016
HQS_5 lame–exciting	0.47	0.000
HQS_6 easy–challenging	-0.19	0.110
HQS_7 commonplace–new	0.45	0.000
PQ_1 technical–human	0.37	0.002
PQ_2 complicated–simple	0.52	0.000
PQ_3 impractical–practical	0.64	0.000
PQ_4 cumbersome–direct	0.53	0.000
PQ_5 unpredictable–predictable	0.39	0.001
PQ_6 confusing–clear	0.55	0.000
PQ_7 unruly–manageable	0.60	0.000
beauty	0.48	0.000
goodness	0.68	0.000
appeal	0.61	0.000
annoyed	-0.56	0.000
bored	-0.46	0.000
confident	0.10	0.424
confused	-0.47	0.000
disappointed	-0.58	0.000
frustrated	-0.58	0.000
happy	0.59	0.000
interested	0.54	0.000
hopeful	0.41	0.001
pleased	0.54	0.000
unsure	-0.26	0.042

Table 5.6: Correlations between PWA and UX dimensions for the Kendall test.

5.4.3 The relationship between UX and web accessibility indicators

The relationships between web accessibility indicators (AIs) and UX dimensions were analysed. The AIs were obtained as a result of evaluating the web accessibility of the websites selected as stimuli with different evaluation methods (see Section 5.2.3).

Based on the outcomes of these evaluations, a list of 37 accessibility indicators was obtained. Those accessibility indicators were derived from four main sources: the TAW online automated evaluation tool (*tool*), the metrics from the WAQM software (*m*), the conformance to WCAG 2.0 (*sc*) and the barrier walkthrough exercise (*bw*). The reason for choosing the results from the TAW online tool was that it provides an straightforward way to discriminate among errors and warnings and their correspondence to WCAG 2.0 principles. Those four main AIs were broken down into more specific indicators resulting in a list of 37 AIs. For example, by separating the errors (*e*), which are the detected accessibility problems, from the warnings (*w*), those potential accessibility problems; considering the four accessibility principles of the WCAG 2.0 guidelines (*perceivable* (*p*), *operable* (*o*), *understandable* (*u*) and *robust* (*r*)); the conformance level (*a*, *aa*); and the number of satisfied (*sat*) and not-satisfied (*nsat*) success criteria (*sc*). For instance, *m_m* represents the average accessibility level in percentages reported by the WAQM, *tool_w_p* refers to the number of warnings reported by the tool for the *p* principle, *tool_e_u* corresponds to the number of errors reported by the tool for the *u* principle, *sc_sat_a* represents the number of satisfied *sc* for the A (*a*) conformance level, *sc_nsat_aa_p* indicates the number of not satisfied *sc* for the AA (*aa*) conformance level for the *p* principle, and *bw* corresponds to the number of barriers found using the barrier walkthrough method.

Due to the exploratory nature of this considered, both, the ordinal and the interval nature of Likert scales were adopted. In order to obtain more reliable results three statistical correlation tests were used to report effect sizes: Kendall, Spearman and Pearson. Even if they are different correlation tests, the same criterion was used for reporting effect sizes. A score between 0.1 and 0.3 signals a small effect, between 0.3 and 0.5 the effect is of medium size, and over 0.50 is considered large. Alpha was set at 0.001 for statistical significance. Different correlation tests are usually not identical in magnitude because their underlying logic and their computational formulas are not equal.

Analysing results for each test separately, and focusing only on large effect sizes, no significant [N=88 (11 participants x 4 websites x 2 web pages), $p < 0.001$] strong correlations among UX dimensions and AIs were found for the Kendall test. For the Spearman test however, strong significant correlations were found for *conservative–innovative* (HQS_4) with six manual AIs, and for *lame–exciting* (HQS_5) with two manual AIs (see Table 5.7).

With regard to results from the Pearson's test, significant strong correlations were found for *isolating–integrating* (HQI_1) with one AI, for *conservative–innovative* (HQS_4) with seven AIs, for *lame–exciting* (HQS_5) with three AIs, for *complicated–simple* (PQ_2) with one AI and *unruly–manageable* (PQ_7) with one AI (see Table 5.8).

In both cases (for Spearman and Pearson), the predominant AIs correspond to the manual AIs representing the conformance to WCAG 2.0 guidelines, and specially the ones related to the number of satisfied and non-satisfied SC for the P principle.

AI	HQS_4	HQS_5
sc_sat_a_p		0.53
sc_sat_a_u	0.50	
sc_nsat_a_p	-0.53	-0.52
sc_sat_aa	0.54	
sc_sat_aa_u	0.50	
sc_nsat_aa	-0.51	
sc_nsat_aa_p	-0.52	

Table 5.7: Significant [N=88 (11 participants x 4 websites x 2 web pages), p <0.001] strong correlations for the Spearman test.

AI	HQI_1	HQS_4	HQS_5	PQ_2	PQ_7
m_u			0.54		
tool_w_u	-0.50			-0.50	-0.50
sc_sat_a_p			0.51		
sc_nsat_a_p		-0.52	-0.51		
sc_sat_aa		0.52			
sc_sat_aa_p		0.50			
sc_sat_aa_o		0.50			
sc_nsat_aa		-0.50			
sc_nsat_aa_p		-0.52			
sc_nsat_aa_o		-0.50			

Table 5.8: Significant [N=88 (11 participants x 4 websites x 2 web pages), p <0.001] strong correlations for the Pearson test.

Significant [N=88 (11 participants x 4 websites x 2 web pages), p <0.001] moderate correlations were also found between UX dimensions and AIs for the three statistical tests performed. In order to provide a general perspective, figures 5.5, 5.6 and 5.7 show a graphical representation of the correlation coefficients obtained from Kendall, Spearman, and Pearson tests respectively.

Each correlation matrix shows that the more and the higher correlations are those with regard to *typical–original* (HQS_1), *conservative–innovative* (HQS_4) and *lame–exciting* (HQS_5) and specially in the manual AIs related to compliance to WCAG 2.0.

It must be noted that some accessibility indicators are indicators of accessibility, like the number of the satisfied success criteria for the A or AA level of WCAG 2.0, or the accessibility level reported by the WAQM metric; while others are indicators of inaccessibility, for instance the number of not satisfied SC, the errors and warnings obtained from the TAW checker or the barriers identified by applying the BW method. This is the reason for the positive and negative signs of the correlation coefficient values.

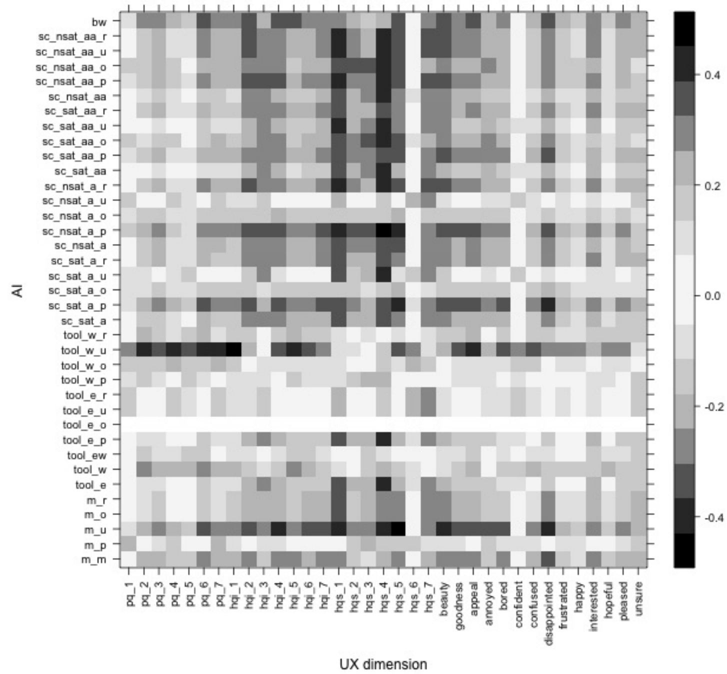

Figure 5.5: Correlation matrix for the AIs and UX dimensions, using Kendall test.

Significant (p <0.001) relationships were found between three UX dimensions (HQS_1: *typical–original*, HQS_4: *conservative–innovative*, HQS_5: *lame–exciting*) with certain AIs representing the conformance to WCAG 2.0 guidelines. Similar results were observed for the performed three different statistical tests (specially with regard to AIs corresponding to the *perceivable* principle of WCAG 2.0), which provides evidence on the existence of the identified relationships.

In addition, Pearson's correlation test was performed using sampling with replacement in order to be more certain of the obtained results. The bootstrapping technique was applied for different numbers of bootstrap replicates (R=100, 500, 1000, 1500, 5000, 10000) for the same confidence level (0.95). No big differences were observed on the confidence intervals de-

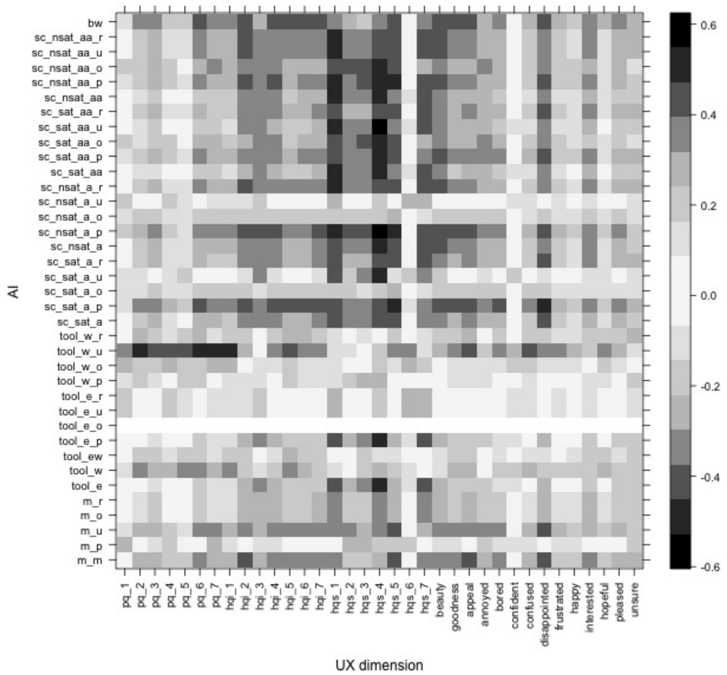

Figure 5.6: Correlation matrix for the AIs and UX dimensions, using Spearman test.

pending on the size of R (the number of bootstrap replicates); but the bias and the standard error are very low, which suggests the similarity with the original estimate. The bootstrapping technique was also applied by relaxing the confidence level (0.90, 0.92). In this case the confidence intervals kept quite stable even when increasing alpha. As the bias and the standard error obtained as a result of applying the bootstrapping technique were very low, none of the confidence intervals included the zero value and the width of the intervals was not very wide, it could be concluded that the identified correlations exist.

5.4.4 Analysing data from interviews

Once statistically significant correlations had been identified among UX dimensions and AIs, the transcriptions of the interviews were analysed in order to better understand the practical importance of the relationships and the reasons why they emerged.

Queries were performed on the transcriptions by using as keywords the synonyms and antonyms of the word-pairs which corresponded to the UX

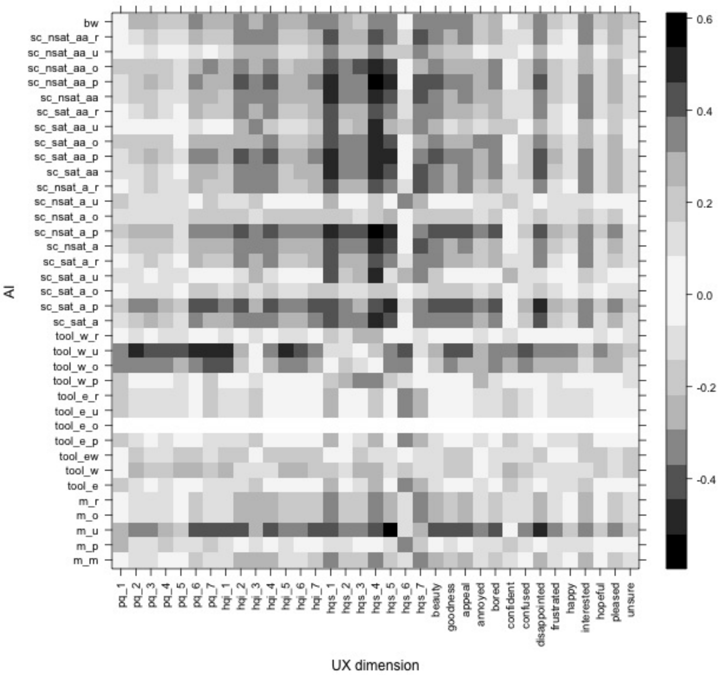

Figure 5.7: Correlation matrix for the AIs and UX dimensions, using Pearson test.

dimensions of the identified correlations. Then, those extracts of the transcriptions where the keywords were found were coded into the corresponding dimension. In order to look for definitions, synonyms and antonyms of the word-pairs corresponding to the identified UX dimensions, different dictionaries were used: the Merriam-Webster online dictionary[8] and the Collins online dictionary[9]. The NVivo[10]http://www.qsrinternational.com (version 10) qualitative data analysis software was employed to facilitate the analysis.

Hedonic quality stimulation: typical–original (HQS_1)

Typical: According to the dictionary, *typical* can be defined as being or serving as a representative example of a particular type, characteristic, having the qualities associated with the members of a particular group or kind. Synonyms (such as archetypal, standard, model, normal, classic, stock, es-

[8] http://www.merriam-webster.com/thesaurus/

[9] http://www.collinsdictionary.com/dictionary/english-thesaurus

[10] \unskip\penalty\@M\vrulewidth\z@height\z@depth\dp¸

sential, representative, usual, conventional, regular, characteristic) and opposites (including unique, unusual, unexpected, exceptional, singular, unconventional, uncharacteristic, out of the ordinary, atypical, unrepresentative) were sought in the transcriptions. Most comments found with regard to both concepts, *typical* and inaccessibility, were related to comments from participants about things that they notice that occur typically or normally. For example, participants may find inaccessible websites regularly. Two expert users (P01, P02) explicitly said that usually there are still many inaccessible websites, specially when it comes to websites of restaurants:

– *"Usually web pages, and more specifically those of the restaurants are not accessible, but especially with restaurants if I find that there are many inaccessible sites (P01)".*

– *"Still very bad, companies are not overly concerned with web accessibility, they are very inaccessible as I said (...) they are horrible (P02)".*

P05 said that W3 was the typical web page in which he would not spend much time if he would have not been participating in the study (e.g. if he would have been at home):

– *"I'd have withdrawn the web page. Yes, yes, this is the typical page I say - out! [snap of fingers] (P05-W3) (...) blind persons are not taken into consideration in web pages (P05)".*

Some users commented common accessibility issues they encountered often. For example, even if a website provides an accessible version, the link which points to it is often at the bottom of the page and thus, is not easy to reach to the accessible version:

– *"In this case it's fine [W1], because I can get to the accessible version (...) normally the buttons for the accessible version are down (...) normally I cannot get to the accessible version (...) it always happens (P02)".*

Problems with links that are not accessible or contain link texts that have nothing to do with the content they point to:

– *"Links that are not accessible in a normal reading (...) is not original, it is not obsolete, I think that is intermediate (P07-W4)".*

Comments were found referring to the normal and alternative versions of websites with regard to the accessibility. Apparently, most participants considered the normal version of websites as the common site where most people access to, which is not particularly adapted to their needs. In contrast, the alternative version (e.g. text only) is regarded as the one accessible for them. Since not all websites have an alternative version, it is not very usual to find one:

– *"It's assumed that the most suitable for us is the accessible one, because the normal is the one that everyone uses (P07)"*.

– *"I don't look for it [referring to the accessible version of a website] because if I knew that all websites have an accessible feature, I assure you that is the first place I would go to (. . .) as we are not able to see, we need the web pages have a number of characteristics which are very specific for us (P08)"*.

Original: Among the definitions found on the dictionary, the adjective is related to something unusual or novel, e.g. not known or experienced before. Synonyms (new, novel, different, unusual, unknown, unprecedented, innovative, unfamiliar, unconventional, innovatory, creative, inspired, imaginative, artistic, ingenious, visionary, inventive) and opposites (old, standard, traditional, normal, usual, ordinary, familiar, typical, conventional, old-fashioned, commonplace, banal, antiquated, unimaginative, unoriginal) were sought in the transcripts.

Most excerpts with regard to originality and accessibility have to do with web content (provided textual information), and a few refer to the layout of the website (how the information is arranged).

The majority of users commented unusual things that draw their attention with regard to content on W1. For example, some referred to the uncommon name of the dishes, as unlike ordinary restaurants, they offered cultural events like live music or theatre to enhance the gastronomic experience.

– *"I found the website funny, I found it very interesting. It called my attention that the guy is in the artistic wave. The mix with the culture, with the theatre, with the music (. . .) (P05-W1)"*.

– *"I think it's an interesting web page, creative, I guess that it has been done with a developed aesthetic sense, with a remarkable originality (. . .) I value that very much (P10-W1)"*.

In addition to textual content, some comments refer to the arrangement of the web content. This may depend on preferences and familiarity with the Web of participants. Gastronomic information in W2 was conveyed through links in a hierarchical multi-level layout, instead of providing the information on the same page, which was not expected by P09:

– *"The menu, I was expecting a document, right? and then of course, it was not a menu as such, it was like a bunch of links (P09-W2)"*.

P02 said that it was unusual to find the link to the accessible version of the website quite at the beginning of the web page in W1:

– *"No, it's not usually the case. And these at least put it high up (...) is quite at the top (P02-W1)".*

The fact that the content was before the navigation menu in W1 attracted P03 participant's attention:

– *"I was struck that when you accessed a link, the information was offered to you at the beginning and then, the rest of the page (P03-W1)".*

P11 was really surprised by coming up with a web form for the bookings:

– *"I found it funny the thing of the bookings, it was a questionnaire that they never do. It has caught my attention. The web questionnaire, rather than booking by email or phone, it caught my attention because I had never heard that, I found it original, and it can still be fine, eh? (...) I've never seen it and the truth is that I got surprised! (...) (P11-W1)".*

Beyond aspects related to web content and layout, some participants valued the novel experience of visiting a restaurant website for the first time:

– *"I had not ever gotten into a page of restaurants, I did not know what it could contain and I really liked it because it was inaccessible but if you try, you get to know new things (P06-W1)".*

– *"I thought it was interesting because I had never entered a restaurant page (P11-W2)".*

Even if many comments were found relating originality and accessibility, they were also found participants' comments with regard to the lack of originality of W2, which was highly accessible:

– *"It's not original, it gets to the point and is very professional, it is not arty (...) the page lacks an artistic touch (P05)".*

– *"Without ambitious filigree which I do not want to underestimate, I appreciate the originality, creativity, I appreciate it, I do not undervalue that, but always in the service of the person in the service of good treatment (P10)".*

This suggests that not only the accessibility of a website, but the quality of the textual content provided on the website is important with regard to the perception of originality. The following extract summarises this idea:

– *"Of course the text meets the objective of informing, and the more interesting the better, I mean that we ignore all the visual part of both the local and the* *dishes, so the things that are interesting for us are the textual explanations (P10)".*

Hedonic quality stimulation: conservative–innovative (HQS_4)

This dimension is closely related to the previous one (*typical–original*, HQS_1). Specially when it comes to the concepts of *original* and *innovative* in terms of novelty and creativity. In fact, many comments coded as *original* were also coded into the *innovative* category. Nevertheless, there is a subtle but important difference with regard to the connotation of concepts. Unlike HQS_1, HQS_4 deals more with conservatism and innovation, which are somehow related to progress and evolution.

Conservative: This term represents a tendency to favour the preservation of established ideas, conditions, values or institutions, opposing innovation. Some examples of synonyms are traditional, conventional, moderate, cautious and reactionary. While liberal, radical, progressive, innovative, and imaginative are some examples of opposites.

Very few but interesting comments that relate both terms, *conservative* and inaccessibility, were found. In line with the definition, P04 suggests that the W3 website is very conservative:

– *"The feeling is that the page hasn't served me for anything, isn't it? in addition to being annoyed I found the feeling that is totally conservative, it has no innovation, is not accessible at all (P04-W3)".*

P05 goes further and refers to a sign of a not evolved society or country, where he assumed that such inaccessible websites are still created:

– *"I think they have not thought much about people who are not able to see, right? About the accessibility, I think nowadays it should already be (...) I'm sure that in the Netherlands these inaccessible websites are not developed any more, but anyhow, we are a poorly evolved country (...) they are so crappy in 2012, and a guy who is loaded and has so much cash to make a website... (P05-W3)".*

Innovative: Definitions for *innovative* include showing a noteworthy use of the imagination and creativity especially in creating new things and inventing. Synonyms include novel, new, original, different, fresh, unusual, unfamiliar, uncommon, inventive and singular.

With regard to comments relating the *innovative* and accessibility concepts, most refer to the content of the W1 website.

- *"What I liked the most has been the innovations as to cultural thing, the adaptability for celiacs and (. . .) that is, the adaptation of diets to special needs. I like that as content. As design I did not like anything. And the least the oddities of the kitchen (P09-W1)".*
- *"To see that it is a different design it has aroused my curiosity (. . .) we are among the inventors of cooking (. . .) what I have liked most is the innovative character. . . (P10-W1)".*

Hedonic quality stimulation: lame–exciting (HQS_5)

Lame: Definitions of *lame* include falling short of a standard, painful or weak, unconvincing, not effective or enthusiastic, conventional or uninspiring. Synonyms include defective, unconvincing, poor, inadequate, weak, insufficient and unsatisfactory.

Most comments found with regard to *lame* were about the W3 website. In fact, at least one comment of each participant was found about W3 in this category, understood as tedious, boring or dull:

- *"It is not easy to handle. The information that it provides you is quite hard to find with a screen reader, unspecific, it's hard to find what you are really interested in. It's too much effort, you waste a lot of time and the specificity, the information you get, is not very reliable I would say. The messy links, were not very enlightening, they do not give an idea of the content in each link (. . .) it was like a labyrinth, too complicated. I had to look carefully for finding something concrete. Many hidden details, I told you that a maze is what comes closest. At the end, to get something specific you would have to invest much time, effort and I'm not sure if one would get to anything concrete (. . .) is a navigation information at the beginning that at the end forces you to have to do all the tour of the entire page. It's like to get a room in a hotel you would have to go through the 360 rooms it has, it seems complicated (. . .) is the most difficult one of the four websites, for a screen reader user is unsatisfactory, it has told me nothing special (P07-W3)".*
- *"You realise that you are in a loop and you cannot exit, you start to doubt if you are clumsy, or the Web does not facilitate things. Then as you are in this situation the hope, disappointment, frustration and all that it gets more intense (. . .) if it wasn't because we are here, I would have left at the second minute. I would not have insisted, because I have to do my part much more than what I find reasonable. I mean, they put you a list of 7 links with images and so which is incredible, they are telling you: but what are looking for, this site is not for you. Since we are working I tried to search, and trying*

and trying I may had found [laughs] but definitely I would not have hold on two minutes at home with this website (. . .) Such a menu based on images is a derogatory barrier, disrespectful. It does not motivate you, nor attract you (. . .) what I disliked the most is that is a fortress for the accessibility, a bunker. . . (P10-W3)".

With regard to W4 only comments from one participant were found:

– *"Disappointed, confused in many moments, completely bored and very annoyed (P02-W4)".*

Even if the majority of the comments about *lame* were about W3, a few more were also found with regard to the more accessible websites, W1 and W2:

– *"It is not a very clear content as to the presented links. It promises, it seems that it will provide information, but the information that exposes is very literary. Very literary and very repetitive for a screen reader. And the information you are looking for is not very specific (P07-W1)".*

– *"At the beginning I had more hope, but it has not convinced me finally (. . .) it's a feeling I would not know how to explain it. It's a web page that has not convinced me (P08-W2)".*

Exciting: According to the dictionary exciting is related to causing great emotional or mental stimulation. Synonyms for exciting would be stimulating, inspiring, thrilling or sensational while opposites include boring, dull, dreary, monotonous, uninspiring, humdrum, uninteresting and unexciting.

Regarding the exciting, stimulating dimension most comments are with regard to the accessible websites, W1 and W2.

– *"I found it attractive the web page (. . .) a desirable place to go (. . .) gives you all kinds of options clearly (. . .) it seems to me that it's a very nice and very attractive site (. . .) a website with very specific and clear information, and very attractive things (section of opinions, the video) (P03-W2)".*

– *"I felt stimulated. When I began to find, pull the thread and find information. I could have spent more time browsing to explore (. . .) as it was possible to find out what there was. Then I felt as familiar, as I was not strange, the page did not repelled me. I liked it, I had fun, it was funny and I felt informed also, I was satisfied because I was informed (. . .) what I liked the most is being informed about the main data, where it is, what I can ask to eat. That the navigation is as easy as we commented and the website gives me information (P09-W2)".*

As further examples of exciting, comments of participants were also found on the possibility of revisitating the website and in some cases participants commented their willingness to go to the restaurant.

– *"I'll check it at home, maybe I'll write them an email telling them that the website is perfect (P06-W2)"*.

– *"The first thing I want to record is that one day we will take a few tapas there. I would like to invite [the experimenter] to take a tapa in Gandarias (...) those tapas we have heard that have stimulated our gastric juices (P10-W2)"*.

Another surprising thing that it was observed is that the attention of some users was attracted by a piece of content in W4. Three participants thought that the content of the homepage of W4 entitled as "*The History*" of the restaurant was particularly interesting:

– *"The history which I didn't know, It caught my attention (P08-W4)"*.

– *"I liked it very much that historical introduction that it provides (P10-W4)"*.

– *"I think that the history was very interesting (P11-W4)"*.

In fact, it was more than a historical introduction of the restaurant, as it also included a brief description of the gastronomic offer, the dining rooms, and the location of the restaurant.

5.5 Discussion

5.5.1 How do blind users perceive and experience web accessibility? (Q1)

Results corroborate that blind users' experienced web accessibility does not always correspond to compliance with accessibility guidelines. In order to better understand the experienced accessibility, how experiential aspects may influence on the users' judgement about the accessibility on websites was studied.

Prejudices, past experiences and memories determine expectations

Before visiting a website most participants already had preconceived ideas and expectations regarding the website, which were mainly about previous experiences either because of having navigated on similar websites, or due to past experiences at restaurants. For instance, three participants who had experienced uncomfortable situations when ordering at restaurants expected the website to provide them with practical information to avoid such problematic situations. Taking measures to avoid awkward situations is an strategy documented elsewhere [94], which indicates that the Web is instrumental for people with disabilities to plan their journeys well in advance.

It was also found that having had an endearing and satisfying experience at a particular restaurant in the past could also influence the expectations about the website of the restaurant. Nevertheless, the actual web experience can also determine real life experiences: some participants showed either willingness to revisit the website and go to the restaurant because their good experience on the restaurant website. On the other hand, they showed no interest on restaurants and their websites if the experience was poor. This provides additional evidence to support a business case for accessibility and user experience.

Preconceptions did not only create expectations, but affected how accessibility was experienced. Participants were more demanding with those restaurants that were better positioned to have an accessible website due to their international prestige, and alleged resources and affluence. In contrast, evoked memories have an impact on the experienced web accessibility as participants rated the accessibility of those websites that evoked fond memories higher. It is suspected that traumatic memories will negatively influence too.

Unmet expectations

While trying to accomplish their tasks participants' expectations were not always met. In general, this happens when there is discrepancy between what was expected and what is encountered. The underlying reasons of the mismatch are due to:

- the obstacles within the website including accessibility barriers, usability flaws and confusing information architecture;
- problems with the screen reader;
- their preferences, previous knowledge, skills and expertise.

Unmet expectations are not always explicitly reported as such: when participants come across with unexpected content or functionalities this is often reported as a problem of the website when actually there is a mismatch between the mental model of users and the model of the website. The existence of accessibility barriers made some content non reachable and therefore non-accessible in this study. Not being able to find such content is not blamed on accessibility barriers which are not directly perceived, but users think that the website does not contain such content or that they were not able to find it. Specifically, intermediate and advanced users take on the responsibility of the failure, while those on the extremes (i.e. experts and beginners) blame external factors such as the website and the screen reader. In the case of beginners they may know fewer things (e.g. basic screen reader commands for web navigation) but well learned, while experts may well know the causes of problems. When it comes to intermediate and advanced participants, they may be aware of the wide range of possibilities offered by the Web but at the same time they know the limits of their own internet skills, which lessens their confidence on their judgements.

The role of uncertainty and confidence

More uncertain situations were found on non-accessible sites than on the accessible ones, which suggests there is a relationship between the lack of accessibility and uncertainty. This finding reinforces the fact that uncertain situations trigger coping strategies [120] and the fact that uncertainty is caused by unmet expectations and accessibility barriers.

While uncertain situations can be triggered when websites are visited for the first time, it was observed that this uncertainty remained after finishing the task. This lasting effect has an impact beyond the perceived accessibility and affects the user experience. Therefore reducing the uncertainty would probably lead to a better user experience. Designing with familiarity and learnability principles helps in removing this uncertainty while may help boosting the experience of users [121]. Understandably, supporting and training users in order to acquire skills will increase their confidence to cope better with uncertainty.

'Accessible' versions of websites

Most non-expert participants said that they usually visit the accessible version of a website if this is available, whereas expert participants reported that they usually access the main version, even on the first visit to the website. Some participants do not access accessible versions of websites that they visit periodically because they said that alternative versions are usually inconsistent, lack information and are not updated as regularly as the main version. Some rejected accessible versions on the grounds of discrimination. Anecdotally, one participant reported that the choice depends on the navigation modality, whether navigation is exploratory or directed. On directed navigation —i.e. the user has a specific goal in mind— the accessible version is more useful. Conversely, if the navigation is of exploratory nature the main version is preferred.

'Accessible' versions do not only arise the curiosity of participants, but creates high expectations about their accessibility. Those webmasters managing different website versions must be careful because if these high expectations are not met, it generates sheer frustration. The above implies that accessible versions of websites should be carefully provided: they should be not only accessible, but easily findable and noticeable. For example they should be included in the results of search engines somehow along with the main website. In addition, if an accessible version exists, the link to access to it should always be easy to find.

These findings have implications on user testing practices in that the isolated aspects influence the assessment and ratings of users (with regard to accessibility) in a considerable way. This phenomena calls for identifying these situations and calibrating assessments and ratings on users tests.

All the identified aspects —i.e. past experiences, prejudices, evoked memories, unmet expectations and confidence— may strongly affect how users perceive and experience the accessibility of websites. Because of this, the experienced accessibility is a highly subjective quality, which does not necessarily correspond to compliance with accessibility standards. Since guidelines are defined for standardisation purposes, their technical specification has, understandably, a unified and integral view of accessibility that can hardly deal with the identified subjective aspects.

5.5.2 Is there any relationship between web accessibility and UX? (Q2)

On the relationship between perceived web accessibility and UX dimensions

Results suggest that perceived web accessibility is associated to most of the UX attributes explored in this study. The strong and moderate significant statistical correlations found between PWA and the attributes belonging to the hedonic quality-identification (i.e. inclusive, presentable, brings me closer to people, professional, integrating, valuable and classy) indicate that participants may feel closer or more identified with websites they experience to be accessible. And the other way around: they may feel more distant from websites perceived as non-accessible, as if these websites were foreign artefacts that are not designed for them.

It was also found a relationship between PWA and pragmatic quality, which represents the usability perceived by participants. A website that participants considered accessible is related to UX attributes, such as practical, manageable, direct, clear and simple and predictable; while a non-accessible perception of a website is related to attributes like impractical, unruly, cumbersome, confusing complicated and unpredictable. Results for the relationship between PWA and the hedonic quality-stimulation attribute indicate that websites experienced as accessible are related to perceptions such as creative, original, exciting and new. In contrast, websites considered to be non-accessible are related to perceptions like standard, typical, lame and commonplace. Findings also support that a positive accessibility perception is related to appraisals of goodness, appeal and beauty. This suggests that a website which is experienced to be accessible is perceived as good, appealing and beautiful, while a non-accessible website is considered as bad, repelling and ugly. In summary, participants perceived positive qualities on websites experienced as accessible, and the opposite effect happened, in websites perceived as non-accessible negative qualities were predominant.

Strong and moderate correlations of PWA with emotion-bearing words were also found. PWA is positively related to emotional words with positive valence (i.e. happy, pleased, interested and hopeful) and negatively related to emotional words with negative valence (i.e. disappointed, frustrated, annoyed, confused and bored). Websites perceived to be accessible trigger positive emotional reactions; while those considered as non-accessible ones trigger negative ones. This indicates that participants may feel better on a website they experience as accessible than when navigating on a website perceived as non-accessible.

These results show that the experienced accessibility of participants is not only associated to perceptions on task-oriented aspects, but also to even more subjective and experiential ones like hedonic aspects, emotional reactions or appraisals on beauty, goodness and appeal. While these outcomes are not surprising, this study provides empirical evidence indicating that perceived accessibility and user experience could be understood as interchangeable qualities for blind users. A practical implication of these findings is about informing the design of instruments and protocols to be used in studies involving users. Because UX attributes are strongly correlated to PWA, UX terminology could be used as an indirect way to elicit information about how users perceive or experience the accessibility of a website on questionnaires, questions on focus groups and interviews. Participants will probably be more familiarised with terms representing UX attributes (e.g. emotional reactions such as disappointment and frustration) than with technical terms about the Web, assistive technologies and accessibility. The identified attributes do not only serve as proxies for perceived web accessibility, but they can also facilitate the communication during user studies, leading to a better understanding of the experience of blind users with a website.

On the relationship between web accessibility indicators and UX dimensions

This analysis revealed evidence to support the relationship between the UX attributes corresponding to the hedonic quality-stimulation *typical–original* (HQS_1), *conservative–innovative* (HQS_4), *lame–exciting* (HQS_5) and AIs representing the conformance to WCAG 2.0 guidelines. It was observed a slight predominance of AIs corresponding to the *Perceivable* principle of WCAG 2.0. Accessible websites (in terms of a higher number of satisfied SC or fewer number of non-satisfied SC) are perceived to be original, innovative and exciting, whereas non-accessible ones (in terms of a lower number of satisfied SC or higher number of non-satisfied SC) are perceived as typical, conservative and lame.

Comments of participants during the interviews provided additional evidence to support the correlations found between compliance to guidelines and three hedonic quality-stimulation attributes: original, innovative and exciting. Participants may consider accessible websites original because they still find many accessibility problems on the Web. Expert users claimed there are still many non-accessible websites (especially restaurant websites) and coming across an accessible website is considered a novelty. In line with this, some users appreciated the uncommon event of encountering alternative and theoretically more accessible versions of websites. It was also observed that the perception of originality is not only influenced by the website's accessibility: the quality of textual content and its arrangement boosted the perception of originality. Nevertheless, cautiousness should be taken about this statement as user expertise and familiarity with the domain seem to play the role of moderator variables.

Accessible websites were considered to be innovative and related to progress and evolution, while non-accessible ones were regarded as conservative. A clear relationship between *lame* and lack of accessibility as well as between *exciting* and accessibility was observed. With regard to *lame*, participants gave some illustrative metaphors which reflect how it is like to navigate on a website with serious accessibility problems: *"a labyrinth, a loop going nowhere, trying each room of a hotel to select just one, a fortress for the accessibility, a bunker..."*. Conversely, participants were strongly motivated on accessible websites, which could lead to website revisitation or even to physically go to the restaurant featured on the website. The experience of accessing a different type of website for the first time may have contributed to some extent to the motivation of participants. This suggests that the hedonic quality-stimulation is not only driven by the characteristics of the stimuli, but by other experiential aspects, such as expectations and previous experiences on the Web. Nevertheless, it was found surprising the fact of the unbalanced number of comments about the *lame* attribute on those websites with low accessibility (more comments were found with regard to W3 than related to W4). One possible explanation for this is that the severity of accessible barriers may have more impact than their number. For instance, W3 did not have proper text alternatives for the navigational image links, which had devastating consequences on the hedonic quality-stimulation attributes. Even if the content about the gastronomic offer was accessible users were totally demotivated when exploring the homepage. On the other hand, the texts of the navigation menu links in W4 were clear and concise although the content about gastronomic offer was not completely accessible. This can be explained in light of previous works that highlighted the importance of the information architecture and the understandability of the texts in navigation menus. Blind users use link texts on the navigation menu to get an overview of websites, as they help them to form a mental model of the website [73].

Few works in the literature relate UX attributes and web accessibility. One exception is the study by [80] where accessibility indicators were computed using the Barrier Walkthrough method and aesthetic judgements were made by sighted users. They found that web pages judged on the classical aesthetics attribute as being visually clean showed significant correlations with accessibility. No correlation was found between the expressive aesthetic attributes and accessibility indicating that an expressive design is not necessarily in conflict with accessibility. In fact, expressive aesthetics [68, 49] match with the hedonic quality-stimulation attribute from Hassenzahl's model. Specifically the *original*, *innovative* and *exciting* attributes map to *original*, *creative* and *fascinating* expressive aesthetics attributes respectively. Hence, these findings do not only corroborate that a expressive design is not necessarily in conflict with accessibility, but additional evidence is provided on the interplay between web aesthetics and accessibility. In this context, web aesthetics should be conceived beyond the visual representation and content of websites. In order to increase the aesthetic perception of websites the information architecture and the quality of texts should be paid attention.

Whether compliance to accessibility guidelines implies a satisfying user experience is a controversial topic. Findings suggest that compliance to guidelines benefits the *original*, *innovative* and *exciting* attributes of the hedonic quality-stimulation attribute. It seems reasonable to assume that an accessible website is more likely to offer users new impressions and opportunities than a non-accessible website. If the content of a website is accessible, users will have more chances to be stimulated and motivated to navigate on that website than on a poorly accessible website.

5.5.3 Implications for design

The accessibility problems participants encountered are those covered by previous works and guidelines [110, 73, 72]. These works provide already a substantial body of knowledge on the design recommendations to build more accessible websites. Findings corroborate how critical information architecture and navigation menus are, how beneficial it is to provide 'skip navigation' links and the effect of text quality of the aesthetic perception of websites. As far as design recommendations are concerned, these findings stress the criticality of the mentioned features in that they do not only improve accessibility, but they also boost a positive perception of websites.

5.5.4 Limitations

Restaurant websites were the object of this study. Following the previously mentioned classification for websites [33], it is hypothesised that the findings are generalisable to those websites that fall into the axes of commercial sites which target a general audience and exhibit an *informative–seductive* communication style. For instance, the websites of products/services such as local shops or charities that appeal to emotions in order to engage the customers.

While the outcomes are applied to blind users, it is hypothesised that the results are generalisable to broader audiences. The role that prejudices, expectations and memories play on the user experience may well be independent of the users' abilities. Thus, the outcomes related to these aspects are the ones that are more directly transferable. The uncertain situations and the design barriers may also impact on able-bodied users, especially on those who are less skilled and knowledgeable about web conventions. However, more evidence is required in order to suggest the generalisability of these outcomes to broader populations.

Results of the study with regard to the identified correlations between web accessibility and user experience could have depended on the selected UX model. It is hypothesised that results would be similar (meaning that identified correlations would be found as well) if another framework had been used, as long as it hold similarities in terms of the measured dimensions.

5.6 Conclusions

Understanding the relationship between UX and web accessibility is a key issue in order to design websites that provide blind users with a better experience on the Web. This chapter, examined the experience of blind users with regard to two different web accessibility perspectives: their subjective experience and more objective accessibility indicators. For this purpose, two research questions were explored: 1) How do blind users perceive and experience accessibility? (Q1); and 2) Is there any relationship between UX and web accessibility? (Q2).

From the analysis conducted for answering Q1, the experiential aspects that influence blind users' perception and experience of accessibility barriers on the Web were identified, including

- prejudices;
- past experiences;
- memories;
- expectations;
- and confidence;

Experienced accessibility is not only an intrinsic quality of websites, but it is also constructed from what individuals preconceive and expect from them. Consequently, these factors introduce subjectivity to the results obtained in controlled user testing protocols. The identification of the factors and calibration of results in order to correct these deviations is critical if reproducible, comparable and reliable results want to be achieved.

With regard to shed some light on Q2, and acquire a better understanding of the interplay between UX and web accessibility, it was analysed the relationships between UX attributes and perceived web accessibility (PWA) and accessibility indicators derived from conformance of websites to guidelines (AIs). Results revealed that most UX attributes (28 out of 35) are significantly correlated with PWA indicating that perceived accessibility is related to hedonic and pragmatic qualities. This work provides empirical evidence indicating that PWA and UX could be understood as interchangeable qualities for blind users. As concepts that belong to these UX attributes (e.g. interested, disappointed, frustrated and annoyed) are probably more familiar to users than technical terms about the Web and assistive technologies, they can be employed to facilitate the communication between researchers in ethnography, contextual enquiry, focus groups or interview studies. This analysis also uncovered significant relationships between three hedonic quality-stimulation attribute pairs (*typical–original*, *conservative–innovative* and *lame–exciting*) and accessibility indicators that represent the number of satisfied WCAG 2.0 success criteria. These attributes can be understood as as proxy measures for web accessibility conformance as far as blind users are concerned. Including these attributes in questionnaires or other sort of enquiry method would be an indirect way to obtain estimates of conformance to accessibility guidelines.

Chapter 6

Conclusions

This Thesis contributes to the web accessibility area from three different perspectives: from the automated adaptation of the evaluation and user interface development point of view, to a more end-user experience related perspective. The aim was to develop tools that will facilitate the work of evaluators and designers, and also to gain a deeper understanding about the subjective experience of end-users when they access the Web.

The main contributions of this work are described below. The way that research challenges, corresponding to each of the three accessibility perspectives covered in this work, have been addressed are enumerated as follows:

6.1 Automatic evaluation

Is it possible to evaluate web accessibility considering context information? Can we build an automated framework which is able to evaluate considering the specific characteristics of access devices?

A device-tailored assessment tool for mobile web guidelines evaluation was developed.

Mobile Web Best Practices 1.0 were released to guide developers when developing web content for mobile devices. These practices rely on the Default Delivery Context (DDC), which refers to the software and hardware requirements a mobile device should meet to provide users with a minimum quality experience on the Web. Those best practices that have a dependency on device features (such as hardware, software, user agents, or even HTTP headers) have been identified and they have been modelled with semantic web notation in order to be univocally referred to and to gain interoperability in the evaluation tool. This way, best practices can be adapted to the specific features of each device, as long as these features are stored in device data repositories. As a result, device-tailored evaluation reports are obtained. Empirical data show that device-tailored results are more precise than the assessment that does not consider the specific device features. The results of this research have been published in [117] and [118].

6.2 Automated development

Is it possible to automatically generate adapted UIs of various services and for different users? Can we build an automated system which is able to generate multiple versions of UIs based on the requirements of users?

An automated user interface generator (the Egoki system) which generates web-based UIs, that are adapted to users needs, was developed. A single UI cannot satisfy the requirements for all users using a different access device, specially in ubiquitous environments, where the potential users cannot be known in advance. As an alternative approach to the "universal design" or "design for all" paradigm, adaptation of UIs can be a solution to benefit different user needs. In the particular domain of the ubiquitous environments, a model based adaptation approach can be a feasible solution for providing users with UIs that satisfy their requirements. Based on an abstract description of the UI of a service and the model of a user and his context, Egoki selects the most suitable multimedia resources for each user, and finally by applying the most suitable adaptation rules, it creates the adapted UI. The use of a system like Egoki could enable that users with disabilities use services that are provided in ubiquitous environments in an accessible way. Beyond the benefits from an end-user point of view, such a system could be of great help for designers and developers. In order to design and develop multiple versions of a UI for each service, by defining just one description of the UI for a service, and by providing the necessary resources in different modalities, the system can generate different version of the UI of a service for different users. This has a wide range of benefits not only for designers and developers of UIs of ubiquitous services, but for the users, who would be able to access these services in an adapted way. This work has been published in [2], [81], [10] and [38]

6.3 User experience

Do accessible websites provide users with a good user experience? How do users experience web accessibility? How are web accessibility and user experience related?

Perceived web accessibility was explored. The experiential aspects that influence blind users' perception and experience of accessibility barriers on the Web were identified, including:

- prejudices;
- past experiences;
- memories;
- expectations;
- and confidence;

Experienced accessibility does not only depend on the intrinsic qualities of websites, but it is also constructed from what individuals preconceive and expect from them. Consequently, these factors could introduce subjectivity to the results obtained in controlled user testing protocols. The identification of the factors and calibration of results in order to correct theses deviations is critical if we want to achieve reproducible, comparable and reliable results.

The relationship between web accessibility and user experience was examined. Understanding the relationship between web accessibility and UX is a key issue in order to design websites that provide blind users with a better experience on the Web. With the aim of gaining new knowledge on the interplay between UX and web accessibility, we analysed the relationships between the UX of 11 blind participants and 1) their subjective experience of web accessibility (perceived web accessibility, PWA); and 2) objective measures of web accessibility (37 different AIs).

The research work reported in this thesis is a novel attempt to examine the relationship between web accessibility and user experience not only for the number of UX dimensions analysed, but also because subjective and objective measures of web accessibility have been considered. Results from the analysis on the relationship between perceived web accessibility and UX revealed that 28 out of 35 UX attributes that were assessed are significantly ($p < 0.001$) correlated with the perceived web accessibility. This suggests that the participants' UX and their PWA are closely related. In fact, results indicate that PWA and UX could be understood as interchangeable qualities for blind users. Focusing on the identified strong correlations it was found that participants' perceived accessibility is mainly related to hedonic quality identification (*inclusive*, *presentable*, *brings me closer to people*, *professional*, *integrating*, *valuable*) and pragmatic quality (*practical*, *manageable*, *clear*, *direct*, *simple*). PWA is also strongly related to *goodness*, *appeal* and emotional reactions (*pleased*, *interested*, *disappointed*, *frustrated* and *annoyed*). As these concepts probably are more familiar to users than accessibility and web related terminology, they could not only serve as proxy indicators of perceived web accessibility, but also they can facilitate the communication when conducting research using ethnography, contextual enquiry or usability tests. This could lead to a deeper understanding of the experience of blind users with a website.

Outcomes of the analysis on the relationship between objective measures of web accessibility and UX, uncovered strong significant correlations between three hedonic quality stimulation attribute pairs: (*typical-original*, *conservative-innovative* and *lame-exciting*) and certain manual accessibility indicators representing the number of satisfied SC of WCAG 2.0 guidelines. These attributes can be understood as proxy measures for web accessibility conformance as far as blind users are concerned. Including these attributes in questionnaires or other sort of enquiry method would be an indirect way to obtain estimates of conformance to accessibility guidelines.

This research has led to the following publications: two technical reports (see Appendix A) and four peer-reviewed papers ([7], [6], [8], [11]).

6.4 Future Work

A number of research lines can be undertaken in order to continue with the work presented in this Thesis and advance in the area of web accessibility.

With regard to the device-tailored evaluations, mobile devices and web technologies have changed tremendously since the presented research work was conducted. Although actually a number of mobile accessibility guidelines can be found, there is no standard guideline set yet about how to make the web content accessible for mobile web disabled users. The W3C admits[1] that the technology landscape has changed in a way that was not fully anticipated during the development of WCAG 2.0. This evolution has led to differences in how people access the Web on mobile devices, which implies that new success criteria that address those situations more specifically are required.

Regarding the automated user interface generator system, more research is required to redesign the implementation of some adaptations in order to be helpful for end-users. An important issue with regard to the generation process is that the number and the quality of the resources that service suppliers have to provide, heavily affects the final user interface that Egoki can automatically generate. Some support material should be created to inform service providers not only about the importance of the quality of the resources, but also to guide them on how to design and create them. Egoki deals with the creation of adapted user interfaces based on the information of the models that have been already populated. Future work should also directed towards how to populate and update the models used by Egoki.

With regard to the relationship between web accessibility and the user experience, understanding how users experience accessibility is a key issue. The identified experiential aspects that can influence blind users' perception of accessibility barriers on the Web could be incorporated into user testing protocols in order to control the subjectivity in user testing. In addition, the user experience attributes that were significantly correlated to the perceived accessibility, could not only serve as proxy indicators of the experienced accessibility but also they could be used to design an instrument to be used in user testing. This would be useful to facilitate the com-

[1] https://www.w3.org/blog/2015/10/work-begins-on-extensions-to-wcag-2-0/

munication and elicitation of information when conducting research using ethnography, contextual enquiry or usability tests. While the outcomes are applied to blind users, it is hypothesised that the results are generalisable to broader audiences. The role that prejudices, expectations and memories play on the user experience may well be independent of the users' abilities. Thus, the outcomes related to these aspects are the ones that are more directly transferable. The uncertain situations and the design barriers may also impact on able-bodied users, especially on those who are less skilled and knowledgeable about web conventions. However, more evidence is required in order to suggest the generalisability of these outcomes to broader populations.

As a first attempt to empirically explain the interplay between web accessibility and user experience, there is still room for improvement. The emerged relationships should be further investigated in order to better understand the nature of these connections. It would be interesting to further investigate blind users' hedonic quality perceptions in order to provide them with more pleasurable and enjoyable web experiences. Further research is required, and this research work has served to uncover some clues that may be worth investigating. For instance, the extent to which compliance to guidelines contributes to a more pleasing experience on the Web, and the influence of other aspects, such as the interestingness of the provided text content, the quality of the navigation menu or the provision of a summary or overview of the content of the website on the homepage.

Findings may also depend on the stimulus material in terms of the character of the websites. For instance, the selected websites can be considered to possess more hedonic than pragmatic quality, since their main objective is to inform and attract potential customers, rather than to provide a service or functionality. This should be addressed in further studies. Generalisation of results may be limited to blind users visiting websites for the first time, and those websites which contain similar characteristics with regard to restaurant websites. Future studies should address the remaining possibility of generalising results to other type of stimuli.

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Appendix A

Technical Reports

1. **Review of the dimensions and measurement instruments for uncovering the relationship between User Experience and Web Accessibility**. Available online at `http://sipt07.si.ehu.es/amaia/reports/EHU-KAT-IK-01-13-4.pdf`
2. **Exploring the Relationship between Web Accessibility and User Experience**. Available online at `http://sipt07.si.ehu.es/amaia/reports/WAUX.pdf`