Exploring Twofold Adaptability to the User Interface
Different Users and Multiple Devices

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Keywords: Adaptable User Interfaces, Inclusiveness, Diversity, Multiple Devices.

Abstract: The Web movement beyond desktop to different devices amplified the possibilities to ensure access to information for all. Nevertheless, the consideration of multiple devices and different user conditions for the applications brings complexity to the design and development processes. On the one hand, some existing tools take into account the design and development of user interfaces according to the target device, but do not consider the diversity in terms of end user conditions (e.g., abilities, preferences, culture, limitations, education). On the other hand, some systems provide the adjustment to users with special needs, but do not adapt to multiple devices. In this paper, we present results of a systematic review on literature to build a roadmap on the twofold adaptability of user interfaces: for different users and multiple devices. The results point out a growing demand for solutions that consider adaptation to both: different users and devices; moreover a distribution of the works per type of adaptation mechanisms found suggest aspects still to be covered in further research in the field.

1 INTRODUCTION

The design and development of Web applications portable to different devices have opened up a huge set of possibilities for uncountable domains, such as social systems, educational systems, literacy development, digital and social inclusion, and so on. Indeed, several organizations around the world have undertaken work programs to establish electronic communication via Web technologies. As a result, such technologies are improving the potential of access to knowledge everywhere and at any time, and are becoming a way for tackling the challenge of providing a participative and universal access to knowledge. The universal access has been considered one of the grand challenges of several International Communities around the world (Hoare and Miller, 2004); (Medeiros, 2008). This challenge is about the use of technologies to ensure the access to knowledge in a participative and personalized way for the citizen, taking into account people´s diversity and, consequently, different users' needs encompassing disability issues as well as social problems (e.g., people living in underserved communities).

Although Web-based solutions represent a way to reach a wide audience, for different reasons, such technologies are not yet reaching everybody. On the one hand, the available development tools take into account the design of user interfaces according to the device target, but do not consider the features of the end users, especially those with special needs (e.g., *Haxe (http://haxe.org)*, *Sencha (http://sencha.com)*, *Foundation Framework (http://foundation.zurb.com*). On the other hand, some systems provide the adjustment to users with special needs, but do not cover the different users' needs and multiple devices. In addition, Web environments are even more complex because they are 24/7 worldwide available environments, demand robustness and are constantly changing requirements. As a result, there is a need for systems that can be generalized for multiple devices and, at the same time, specialized for users with different needs, as presented in Figure 1. The main features to be considered during the adaptation of an interface are: i) device type which defines the features and restriction of each device, such as size, hardware, language, and others; ii) adaptation type according to

Bittencourt I., Baranauskas M., Dermeval D., Pereira R. and Braga J..
Exploring Twofold Adaptability to the User Interface - Different Users and Multiple Devices.
DOI: 10.5220/0004418700380045
In *Proceedings of the 15th International Conference on Enterprise Information Systems* (ICEIS-2013), pages 38-45
ISBN: 978-989-8565-61-7

the hypermedia adaptive theory (Brusilovsky, 1996) and software requirements needs; iii) adaptation time, which represents the moment the adaptation should occur; iv) adaptation techniques, which could be represented as the computational techniques used to adapt the interface or to design/create adaptable interfaces; v) goals, which describe the domain goal; and vi) users' needs, which represent the particularities of each user intended to adapt the application.

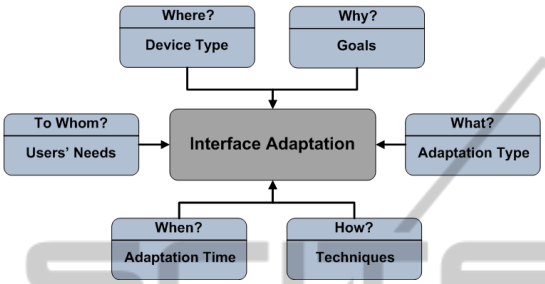

Figure 1: Interface Adaptation mechanisms.

For this reason, several research and industrial studies have been proposed to support the design of adaptive systems that can change aspects of their structure, functionalities, and/or interface in order to accommodate the different needs of individuals or groups of users and the changing needs of users over time (Benyon and Murray, 1993).

As far as we know, no systematic review was conducted to provide an overview on the design and development of systems that adapt the user interface based on the different users needs and for multiple devices. The goal of this paper is to present results of a systematic review on literature to build a roadmap on the design of adaptable user interfaces for different users and multiple devices.

2 THE METHOD

The research in this work was undertaken as a systematic literature review (SLR) to provide a repeatable and formal process for documenting relevant papers about the design of adaptable user interfaces for different users and multiple devices.

According to (Kitchenham, 2004), a systematic review is composed by three phases (planning, conducting, and reporting) divided in several steps, which are: 1) Planning the Review (Identification of the need for a systematic review; Development of a review protocol); 2) Conducting the Review (Identification of research; Selection of the studies; Study Quality assessment; Data extraction and monitoring; Data analysis; Data synthesis); 3) Reporting the review (Report-writing).

2.1 Review Questions

Although many research and industrial studies have been proposed to design interfaces for multiple devices — such as (Calvary et al., 2003); (Gajos et al., 2010); (Falb et al., 2009) — no systematic review has been conducted to provide an overview on the design and development of inclusive environments which adapt the user interface based on the different users' need and for multiple devices.

As the goal of this systematic review was to gather the knowledge about the design of inclusive environments for different users and multiple devices focusing on adaptation capabilities, the high-level question of this study was:

How researchers are designing adaptable user interfaces for different users and multiple devices?

This high-level question provides a starting point for understanding how designers conduct the interface adaptation taking into account the final user. Based on this research question, two other more specific questions were raised. The questions and their motivations are described in Table 1.

Table 1: Research Questions and motivations.

Research Question	Motivation
RQ1. Which Interface Design approaches and support tools are being used to adapt user interfaces for multiple devices and users with different conditions?	The answer to this question is important to understand how people with different conditions are being considered in the interface design process and the different solutions for building applications adaptable for all.
RQ2. Which mechanisms are being used to adapt user interfaces for different users and multiple devices?	The answer to this question is important to identify the different aspects for adapting an interface to the user (as presented in Figure 1).

2.2 Sources and Search Selection Criteria

The first step in performing the review was to define the search selection criteria. Due to the fact that this review has several sources to consider, two kinds of search strategies were considered (i.e., the automatic and the manual search).

The automatic search was done according to the specification of the search terms (i.e., search string). Although the automatic search covers a huge range of relevant papers, it is also important to search on specific and specialized sources to improve the coverage. For this reason, a manual search on some of

the most important conferences and journals of HCI area was conducted.

Hereafter, the search terms definition and the digital libraries (DLs) selection regarding the automatic search are explained. Based on the research questions, a set of relevant terms was defined, such as: *cross-device, disabilities, underserved communities, interface design approaches, multiple devices, different users, tools,* and *inclusive*. After that, such terms were categorized and their related terms were identified. The terms were identified based on: i) the expertise of the authors; ii) the analysis of terms present in a HCI systematic review (Almeida and Baranauskas, 2012); and iii) the *TagCloud* for HCI presented in (Buchdid and Baranauskas, 2012). By contrast, the set of digital libraries was defined according to the most popular and traditional DLs: ISI Web of Science, Scopus, ACM Digital Library, IEEE Xplore and ScienceDirect. The SpringerLink digital library was excluded due to search restrictions. After the definition of the relevant terms and DLs, the search string for automatic search on the mentioned digital libraries was built as follows:

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((tool OR environment OR framework OR authoring OR architecture OR software OR ambient OR "reference model") AND
(inclusive OR inclusiveness OR inclusivity OR "inclusive web" OR "inclusive social web" OR accessibility OR disability OR disabilities OR assistive OR underserved OR "marginalized communities" OR "design for all" OR "universal access" OR "universal design" OR "designing for diversity" OR "design for diversity" OR "design diversity" OR diversity) AND
("Multiple Device" OR "Cross-device" OR "Multimodal" OR migration OR "different devices" OR "device-independent" OR "migratory interfaces" OR "distributed interfaces" OR "plastic user interfaces" OR "flexible user interfaces" OR "flexible interfaces" OR "distributed user interfaces" OR portability OR "portable web applications" OR "portable systems" OR "information interoperability" OR "knowledge interoperability") AND
("Interaction design" OR "adaptable interface" OR "adaptable user interfaces" OR "interaction resources" OR "responsive web design" OR "universal design" OR "inclusive design" OR "process model" OR "adaptable model" OR "meta-design" OR "meta design" OR metadesign OR "participative design"))
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Moreover, in order to perform the manual search, two relevant conferences and journals on Human-Computer Interaction area were considered, as depicted in Table 2. Although this is only part of relevant vehicles, this limitation is due to lack of access to the library of some journals, such as the International Journal of Human-Computer Interaction. Regarding the conferences, some would desbalance the study; for example, the ACM SIGCHI Conference on Human Factor in Computing Systems would represent half of the whole search space.

Table 2: Relevant sources on HCI considered in the search.

Journals
1. International Journal of Human Computer Studies
2. Interacting with Computers
Conferences
1. IFIP INTERACT
2. Cross-Disciplinary Conference on Web Accessibility

2.3 Inclusion and Exclusion Criteria

The aim of defining a criterion is to identify the primary studies that provide direct evidence about the research questions and also to reduce the likelihood of bias (Kitchenham, 2004). Regarding the inclusion criteria, articles written in the last ten years related to any of the research questions were considered. The exclusion criteria involve papers not related to the research questions, papers that were not written in English, short papers, duplicate studies and papers before 2002. The summarized inclusion and exclusion criteria are presented in Table 3.

Table 3: Inclusion and exclusion criteria.

Inclusion criteria
Peer-reviewed studies that answers to the research questions
Studies that focus on design approaches and tools to adapt interfaces for multiple devices
Studies that focus on design approaches and tools to adapt interfaces for different users' needs
Studies published from 2002
Exclusion criteria
Short-papers
Non peer-reviewed studies
Studies that are not related to the research questions
Studies that do not consider user interface adaptation
Duplicated studies
Papers not written in English
Studies before 2002

2.4 Data Extraction

After the definition of the search and the selection processes, a data extraction process was performed by reading the abstract and full-text screening each one of the selected papers. It is important to note that this clustering is based on Figure 1. In order to guide this data extraction, the data collection from Biolchini et al., (2005) was adapted as follows:

- **Paper Information:** Study Reference (ID); Source; Year; Source Type (Journal or Conference); Affiliations; Authors list; Paper Title; Google Scholar Citation;
- **Context** (Industry and Academia);
- **Adaptation Mechanisms:**
  - **Where – Device Types** (Desktop, Web, Tablet, TV, Mobile Phones, PDA, Tabletop, Braille Notes);
  - **Why – Adaptation Goals:** domain-dependent or domain-independent;
  - **To Whom – Users' Needs (Target Audience):** Blind/Visual Impairment; Deaf/Hearing Impairment; Motor/ Mental; Underserved people; Elder;
  - **What – Adaptation Type:** Content presentation; Navigation support; Screen structure; System requirements;
  - **When – Adaptation Time:** Design time; Use Time;
  - **How (1) – Interface Design Approach:** User-Centered; Task-Centered; Participatory; Scenario-Based; Ethnographic Methods; Design per Target; Model-based; Automatically Generated; Multi-tier; Universal Design; User Sensitive Inclusive Design;
  - **How (2) – Tool Technology**: API; Design Pattern; Framework; Platform; Software Product Line; Authoring; MDA; Reference Model; Middleware; Architecture;
  - **How (3) Adaptation Process** – Manual; Hybrid (User and Software Adaptation).
- **Study Type** (Controlled experiments; Quasi-experiments; Case Study; Survey; Ethnography; Action Research);

3 OVERVIEW OF THE INCLUDED STUDIES

This section presents the included studies according to the automatic and manual search (see Figure 2). Firstly, the automatic search was conducted to each digital library. Then, an iterative process was applied to exclude the not relevant papers based on the exclusion criteria. The exclusion criteria were applied according to the analysis of the abstract, full-text screening and, finally, the duplicate papers. A similar process was applied to the manual search. At the end, only 2.19% of the selected papers were considered relevant to this systematic review. The list of the 89 studies is available at www.nees.com.br/iceis.

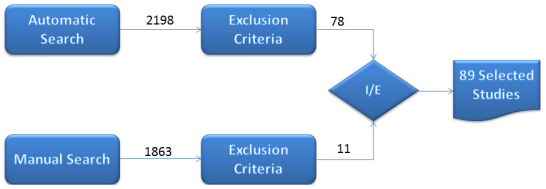

Figure 2: Search process and selected studies.

The automatic and manual queries were conducted in the period between December 4th (2012) and January 11th (2013). The manual search indicated the W4A Conference (55%; 6 studies) as the largest vehicle of relevant studies, and the IFIP Interact (9%, 1 study) as the smallest vehicle of relevant studies. However, other vehicles were identified as relevant when the automatic search was applied, such as the International Conference on Computers Helping People With Special Needs (7.69%; 6 studies), Interacting with Computers (6.41%; 5 studies), ACM SIGACCESS (6.41%; 5 studies), International Conference on Universal Access in Human-Computer Interaction (5%; 4 studies), and ACM SIGCHI (3.85%; 3 studies).

From a temporal point of view, an increasing number of publications in the context of this review is noticed since 2005 (see Figure 3). It is important to note also that 2012 is the year with more publications, which shows a demand for solutions to provide adaptable user interfaces for multiple devices and users with different needs.

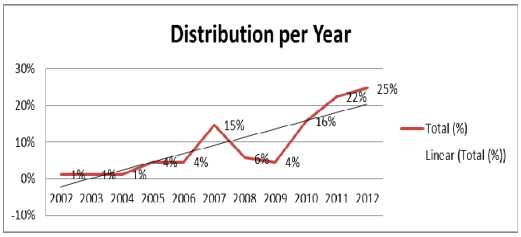

Figure 3: Distribution of publications per year.

As this review has started on December 2012, it would be expected a decreasing in 2012 publications because some papers might be under publication processes. Nevertheless, we can see, in general, an increase in the number of publications (based on the linear progression). Despite this increase, only 2 studies have more than 60 citations (see Table 4); they are depicted in Table 5.

The significant increase in publications reflects the need for convergence of technologies and, at the same time, the importance of deploying inclusive solutions.

Table 4: Publications per number (nº) of citations.

nº < 20	20 <= nº < 40	40 <= nº < 60	Nº >= 60
77	6	4	2

Table 5: List of studies with more than 60 citations.

Study (ID)	Title	Citations
SSD05	A Unifying Reference Framework for multi-target user interfaces	491
SACM64	Automatically Generating User Interfaces Adapted to Users' Motor And Vision Capabilities	61

The study holds contributions from 29 countries located in all the continents. Although all the continents are represented by the included papers, there is a concentration in the Europe (67.62%) and American Continent (20.00%). Table 6 presents the publications per country. Furthermore, according to the distribution of the included papers, most of the related studies were published in conferences (66.29%), while (33.71%) are published in journals, considering the automatic and manual search.

4 RESULTS

As described in Section 2, three research questions have driven this systematic review. Based on the research questions, the string search was built and the type of data extraction defined. Figure 4 presents the type of empirical study of each included study. More than 50% of the works report a case study as empirical evaluation. Less than 20% of the works report some kind of experiment. By contrast, survey studies were 15%.

Table 6: Publications per country.

Country	Works	Total (%)
United Kingdom	13	12.38%
United States of America	12	11.43%
Spain	11	10.48%
Brazil	7	6.67%
Portugal	6	5.71%
France	5	4.76%
Germany	5	4.76%
Italy	4	3.81%
Greece	4	3.81%
Finland	4	3.81%
Sweden	4	3.81%
Others	30	28.58%

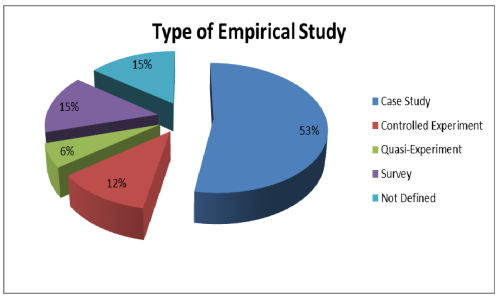

Figure 4: Distribution of empirical study type.

4.1 Adaptable User Interfaces

According to the data extraction, most users' conditions addressed were Blind or Visual Impairment (26.45%; 41 studies), Motor (16.13%; 25 studies) and Mental (15.48%; 24 studies). It is worth noting that although blind and underserved are, respectively, the more and the less discussed conditions, the other disabilities are well balanced (see Figure 5).

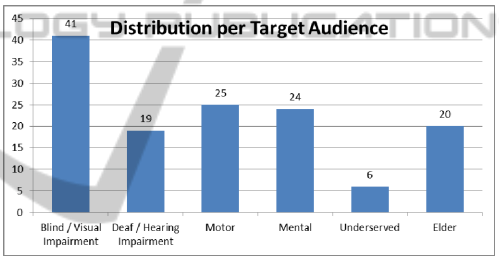

Figure 5: Distribution of the studies per target audience.

Table 7: Distribution per device type.

Device type	Works	Total(%)
Mobile Phones	46	34.06%
Web	25	18.12%
Desktop	18	13.04%
PDA	18	13.04%
Tablet	13	9.42%
TV	7	5.07%
Others	10	7.25%

Table 7 presents the distribution of the papers according to the device type. Most of the solutions were proposed to mobile phones (34.06%; 46 studies) and Web (18.12%; 25 studies). It is worth noting that the number of solutions for tablets is still low (9.42%; 13 studies); it may happen especially because tablets have become popular more recently than mobile phones. On the other hand, although the number of studies for TV is not high (5.07%; 7 studies), one would expect its increasing over time due to new platforms for SmartTV.

Table 8 presents the distribution of work per support tool type. Frameworks, platforms, and refe-

rence models are in the top of the list, while some approaches are not mentioned. In Table 9, it is possible to see that the "Automatically Generated" is the most common ID Approach.

Table 8: Distribution per support tool type.

Tool type	Works	Total(%)
Framework	24	26.97%
Reference Model	15	16.85%
Platform	15	16.85%
Application	14	15.73%
Architecture	6	6.74%
Authoring	2	2.25%
API	2	2.25%
Design Pattern	1	1.12%
MDA	0	0.00%
Middleware	0	0.00%
Software Product Line	0	0.00%

Table 9: Distribution per Interface Design Approach.

ID Approach	Works	Total(%)
Automatically Generated	18	23.68%
User-Centred	15	19.74%
Participatory	13	17.11%
User-Sensitive Inclusive Design	8	10.53%
Task-Centered	5	6.58%
Design Per Target Device	5	6.58%
Model-Based	4	5.36%
Ethnographic	3	3.95%
Others	5	6.58%

Table 10: List of studies that propose support tools and/or applications for users with different conditions and multiple devices.

Study	Paper Title	Tool Type
SACM27	MyUI: Generating Accessible User Interfaces from Multimodal Design Patterns Automatically Generating User Interfaces	Framework
SACM64	Adapted to Users' Motor And Vision Capabilities	Platform
SACM68	Accessibility of Dynamic Adaptive Web TV Applications	Framework
SIEEE11	A Framework for Designing Flexible Systems	Framework
SIEEE30	i*Chameleon: A Unified Web Service Framework for Integrating Multimodal Interaction Devices	Framework
SSCOPUS38	A Novel Design Approach for: Multi-device Adaptable User Interfaces: Concepts, Methods and Examples	Framework
SSCOPUS80	Assistive smartphone for people with special needs : The Personal Social Assistant	Application
SSCOPUS85	Attuning speech-enabled interfaces to user and context for inclusive design: technology, methodology and practice	Application

In contrast, only 18.18% (8 studies) among the selected propose adaptable user interfaces tools for multiple devices. Table 10 depicts these works by presenting their study reference, paper title and the tool type used.

4.2 Discussion

The twofold adaptability meant in this work refers to the user interface; i.e. we were interested in the way the adaptation occurs in the tools that proposed a solution to different users and multiple devices. In general, only a very limited number of papers (8 studies, as presented in Table 10) was identified from the whole list of included studies (see Figure 2), representing 8.98%. It is worth noting that all these 8 papers were published in the last 5 years; at the same time 2012 has the highest number of studies (37.5%). This information demonstrates the current (and growing) interest of the HCI community with the development of solutions capable of adapting users' interfaces for multiple devices and different users conditions.

In order to answer the research questions raised in this work, Figure 6 presents the distribution of papers according to the following six dimensions considering interface adaptation: (i) "where?"; (ii) "why"; (iii) "what?"; (iv) "how?"; (v) "when?"; and (vi) "to whom?".

The "how?" dimension may be especially helpful to answer the RQ1 (*Which Interface Design approaches and Tools are being used to adapt user interfaces for multiple devices and users with different conditions?*). The distribution on how the studies provide interfaces adaptation is characterized by interface design approaches (1), tool type (2) and adaptation process (3). Hereafter, the results considering the interface design approaches and tool types categories are discussed; the adaptation process – as well the other dimensions – will be discussed under the perspective of RQ2.

Thus, Figure 6 shows that automatic generated approach represents only 1/3 of the total, indicating that most of the studies presented manual adaptation (in this review, 62.5%). Conversely, the participatory and universal design approaches are representative, which could indicate the application of more than one approach to enhance the adaptation.

Regarding the support tool type, more than a half of the studies used framework as software design approach. On the one hand, this is expected because frameworks may support the extensibility of software which can be used to adapt different configurations of users' interfaces. On the other hand, the use

of frameworks shows the adaptation is done only by designers/developers not the end users. It is important to note that none of the studies presented software product lines, model-driven architecture or middleware as support tool type. This absence may suggest some kind of detachment between the HCI researchers (related to adaptive user interfaces for multi-users and multiple devices) and Software Engineering, since these approaches are some of the best practices of software engineering research regarding software reuse, flexibility, and dynamic evolution.

Aiming at answering the RQ2 (*Which mechanisms are being used to adapt user interfaces for different users and multiple devices?*), the adaptation process – "How?"(3) – applied in the studies need to be analysed. As Figure 6 shows, 62.50% of the studies present manual adaptation; whilst 37.50% present hybrid (automatic and manual) solutions. The interface adaptation technique is very close to the adaptation time ("when?"), i.e., all studies that apply manual adaptation also provide adaptation at design time; in contrast, all hybrid adaptation studies present adaptation both at design time and runtime. Moreover, it is worth noting that the number of studies that uses frameworks is very similar to the number of studies providing adaptation at design time; this information may suggest that the studies that present framework also implement it at design time. Alternatively, it can also be noted a similar distribution in the automatically generated interface design approach studies. In fact, it is usual that studies that support adaptation at runtime also provide automatic generation of users' interfaces.

Additionally, the outcomes show a regular distribution in the number of studies regarding the target audience ("to whom?"). The impairments disabilities have similar percentages (with slightly higher to blind/visual impairments). At the same time, the elder audience is somewhat attended by the studies (only 7.41%) and the underserved audience is not addressed at all by the identified studies.

Considering the devices types ("where?") addressed in the studies, the appearance of mobile phones is highlighted. The desktop and PDA devices are also representative in the studies. A smaller amount of works focusing on TV or Web (only 11.76%) is observed, while none of the 8 studies took into account the tablets.

The analysis of the studies found three different adaptation types ("what?") for users' interfaces: i) in the content presentation (e.g. font size and colour), ii) in the screen structure (e.g. buttons position according to screen density) and iii) in the system requirements (e.g. check appointment). Figure 6 shows that the number of studies found by each adaptation type are similar, with a slightly decrease in screen structure. Such distribution shows the importance and relevance of the different kinds of adaptation.

Finally, it can be noted a concern ("why?") of the researchers to provide domain-independent tools (75%) in designing users' interfaces for multiple devices and users.

4.3 Threats to Validity

This section discusses the threats to validity that might have affected the results of this systematic review. The review protocol was validated to ensure that the research was as correct, complete and objective as possible. However, possible limitations in the publication selection and in data extraction of the process may have occurred.

The search for publications was performed in two major steps: (i) automatic search and (ii) manual search. In the step (i), there is a limitation because the search string could not be used in SpringerLink library, which possibly leads to a reduction in the considered studies. In the step (ii), there is a limitation concerning the papers included in the review. The manual searching was only performed in a limited set of journals and conferences. Although it was expected that relevant studies published in other journals or conferences would be captured through the automatic search realized in the previous step, it cannot be guaranteed that all related papers published are included in this systematic review.

5 CONCLUSIONS

The design and development of Web applications for different devices have opened up a huge set of possibilities for uncountable domains, such as social systems, educational systems, literacy development, and so on. This paper presented a systematic review to raise the adaptation mechanisms being considered in the development of portable systems. Thus, the study involved data extraction in order to answer the two research questions. A systematic review protocol was defined and the search returned 4061 studies undertaken between 2002 and 2012. After applying the exclusion/inclusion criteria, it leads to the inclusion of 89 studies in the review. After that, only 8 studies fulfilled the defined requirements, which indicate a demand for more research results in the context of the questions addressed in this paper.

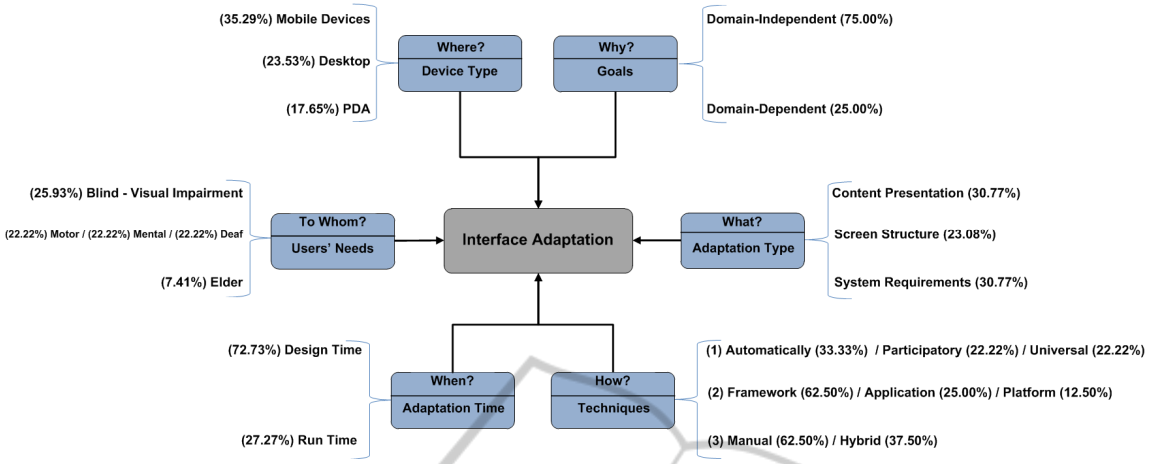

Figure 6: Distribution of studies by interface adaptation mechanisms.

The results indicate that: i) there is a growth in interest of the HCI community in the development of solutions capable of adapting users' interfaces for multiple devices and diverse users; ii) the tools are commonly directed to the technical developers; iii) none of the studies presented a solution to underserved audience; iv) there is a communication gap between the Software Engineering and the HCI communities; in the same way, software engineering approaches need to consider inclusiveness as an important non-functional requirement; v) there is a trend in adapting interfaces to mobile devices; and vi) the researchers are considering both adaptation in the hypermedia and in the systems requirements.

As further work, we expected to: i) diminish the threats to validity in this study; ii) extend the study to consider more papers of relevant authors identified in this systematic review; and iii) analyse the studies according to each type of user condition.

ACKNOWLEDGEMENTS

This work has been supported by the Brazilian Institutions: "Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq)", processes: 150113/2013-7 and 560044/2010-0 (ecoWeb Project).

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