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May the patterns be with you: a framework for HCI patterns development

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Abstract. By the end of the nineties, the concept of design patterns became a hot topic among the human-computer interaction community and many workshops have been held on the subject within international HCI conferences. After more than twenty years, HCI patterns continue to attract the attention of researchers around the world, but still struggle to be more widely adopted as a practical design tool. To better understand this context, we conducted a systematic literature mapping including papers from the ACM CHI Conference and from other five reputed HCI conference series. Through the analysis of 50 papers, we were able to elicit regional aspects, common terminology, and best practices for the research of patterns in HCI. Finally, based on the findings of the literature mapping, we propose an HCI pattern development framework that can assist researchers and professionals in the process of developing practical and useful pattern languages in a structured way.

Keywords: Human-computer interaction · Design patterns · Pattern languages · Systematic literature mapping · Framework.

1 Introduction

Initially conceived by Alexander for the area of Architecture [2], the concepts of patterns and pattern languages were subsequently adopted in a few other disciplines, receiving special attention from the software engineering community. By the end of the nineties, human-computer interaction (HCI) researchers drew their attention to the potential applications of both concepts in the process of interaction design, so much that workshops on the subject became regulars in HCI conferences. Currently, despite controversies on HCI patterns utility and effectiveness, interaction patterns are a widespread idea, known to most designers, user experience (UX) professionals and HCI specialists.

Notwithstanding the attention devoted to the topic in the last two decades, few studies have been conducted with the objective of tracing back the evolution of interaction design patterns and consequently understanding how this concept is being used within the HCI community. Evidence points towards low adoption rates in real projects [28, 76], even though the technique is still considered of interest by the scientific community [55]. According to Pan and Stolterman, proposals of pattern languages in HCI rarely serve as real practical design tools and the languages that have been developed are usually not deployed in large scale [76].

Nonetheless, results based on interviews with researchers indicate that there are aspects of pattern languages that make them interesting from a research point of view [76]. In another work, Kruschitz and Hitz used an online survey to assess the status of design patterns usage among HCI researchers and professionals, in which 40% of the participants responded they had never used HCI patterns before, whereas some alleged that "patterns are difficult to find and that there exists no specific design patterns for their domain" [54]. Regardless of this apparent low usage rate of interaction patterns, few studies have been found aiming at understanding, formalizing, and improving the process of pattern development in HCI.

To better understand how the HCI community is applying patterns and pattern languages in its projects, we conducted a systematic literature mapping focusing on the proceedings of six reputed HCI conference series. By restricting the venues to HCI conferences we were able to obtain the particular view of HCI researchers to the topic. Also, by selecting conferences from different regions of the world it was possible to obtain a broader view and observe regional aspects based on the results from distinct communities. Results of the mapping allowed the extraction of important information such as common terminology and frequently used methods, originating a framework for the development of new patterns and pattern languages in HCI. Our contribution can serve as an important aid to anyone looking for a better identification process of HCI pattern languages, potentially mitigating the barriers that still hinder a wider adoption of this technique in real projects.

This paper consists of seven sections including this introduction. Background on HCI design patterns and related work are presented in Sections 2 and 3 respectively. The planning and conduction of the literature mapping are presented in Section 4. Section 5 contains the results of the mapping, followed by the description of the proposed framework in Section 6. Finally, Section 7 presents final considerations and future work.

2 Design Patterns and Human-Computer Interaction

This section presents definitions, brief historic, and standards of design patterns and pattern languages in the context of human-computer interaction. In summary, a design pattern is a general and reusable solution to a commonly occurring problem. An organized collection of design patterns that relate to a particular context is called a pattern language. Both terms were coined by the architect Christopher Alexander in his seminal work *A Pattern Language* [2]. In the years following the publication of the book, the pattern approach attracted the attention of other groups expanding into further areas of research.

One of the first mentions to patterns in an HCI work can be found in the highly influential book *User Centered System Design* edited by Norman and Draper in 1986 [74]. It was not until the end of the nineties, however, that the topic gained importance among researchers. In 1997, a workshop on the subject was held in the Association for Computer Machinery (ACM) Conference on Human Factors in Computing Systems (CHI), becoming an important milestone, and creating expectations on the future of the topic within the community [11]. Interaction design was becoming an increasingly complex and diverse activity and participants

of the workshop envisioned that patterns could become an important tool and possible solution to the challenges emerging at that time [11].

Three years later, in 2000, a second workshop to deepen the subject was held in another edition of the conference [43]. Borchers conducted a panel at CHI'01 exploring even further the implications of design patterns for HCI [18]. Additional workshops on the topic occurred in editions '02, '03 and '04 of CHI [35, 85, 96]. Around the same time, similar workshops were being held in other conferences such as ChiliPLoP [15], INTERACT [17], and IHM-HCI [42].

It did not take long for the first pattern languages to appear in the HCI area. The more general proposals by Tidwell [91, 92] and Van Welie [95, 97] became the best known and gave rise to the online libraries Common Ground [1] and Welie.com [2] respectively. Subsequent efforts resulted in languages for specific platforms, including web interfaces [86], digital TV [56], and mobile user interfaces [72, 73]. Finally, design patterns were also applied in other areas related to HCI, such as ubiquitous computing [57], cooperative interaction [63], e-learning [79], and learning design [58, 81]. With such variety of application domains, some challenges emerged, such as defining the best structure for pattern descriptions.

When Alexander first defined the concept of pattern, he described a recommended format in which patterns should be written [2]. This format came to be known as the *Alexandrian Form*, was very influential in the development of the topic, and is still widely cited and used today. Despite being a very narrative form, Alexander defined the following basic elements for a pattern description: *number*, *name*, *confidence level*, *picture*, *context*, *problem summary*, *problem*, *solution*, *diagram*, and *relation to other patterns*. Fig. 1 shows visual aspects as well as required attributes of patterns as defined by Alexander in *A Pattern Language*.

With the growing adoption of patterns by software engineers, some authors moved from a narrative form to a more structured form. Following this tendency, Borchers proposed one of the first formal descriptions of an interaction pattern language [16]. According to him, an HCI pattern should be defined in terms of the following attributes: *name*, *ranking*, *illustration*, *problem*, *forces*, *examples*, *solution*, and *diagram*. A pattern language is, in turn, defined as a directed acyclic graph in which the nodes are the patterns pertaining to the language. The graph edges represent the patterns relationships: the *context* of a pattern is represented by edges pointing to it from higher-level patterns; accordingly, the edges leaving a pattern represent the *pattern references* and show what lower-level patterns can be applied after it has been used [16]. See Fig. 2 for an example of the graph-like structure proposed by Borchers.

[1] https://www.mit.edu/~jtidwell/common_ground.html

[2] http://www.welie.com/

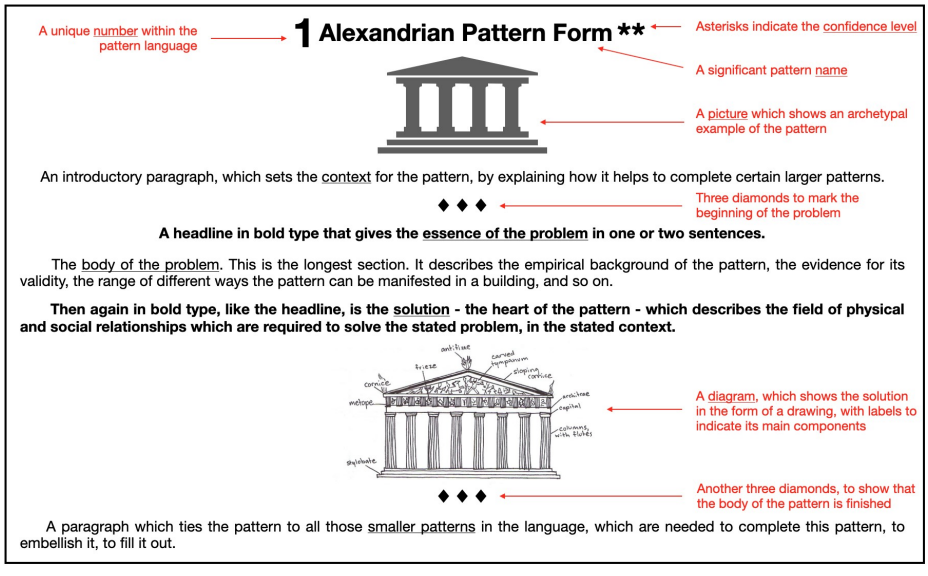

Fig.1. The Alexandrian Form (adapted from Goodyear et al. [40]): visual aspects and required attributes for the pattern presentation as defined by Alexander [2].

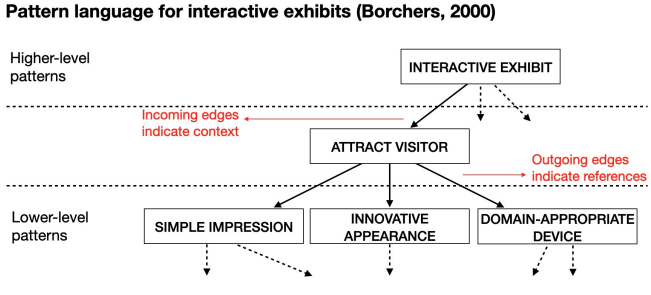

Fig.2. The network structure proposed by Borchers for pattern languages [16].

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A further attempt towards pattern structure standardization is the Pattern Language Markup Language (PLML) developed at the CHI'03 workshop [35]. Designed to be a complete language for patterns description, PLML is still more extensive than the Borchers definition, adding the following attributes to the pattern structure: *synopsis*, *rationale*, *alias*, *literature*, and *implementation*. PLML also defines three types of pattern relationships: besides the Borchers concepts of context (*is-contained-by*) and pattern reference (*contains*), the language also provides for the *is-a* relationship, meaning that the pattern is the same as, or is an alternative solution to the same problem. Finally, PLML contains a series of elements that indicate authorship and change management: *author*, *credits*, *creation-date*, *last-modified*, and *revision-number*. A complete description of the language and the Document Type Definition (DTD) for PLML can be found in the workshop report [34].

3 Related Work

Although not very numerous, some secondary studies on HCI patterns can be found in the literature [28, 53, 55]. The work of Dearden and Finlay [28] is the most complete one with a full description of the early publications and is still a good source of information on the subject, even though it is now over 15 years old. Their review explores four key issues: *What is a pattern? What is a pattern language? How are patterns and pattern languages used? How are values reflected in the pattern-based approach to design?* As a conclusion, authors propose a future research agenda for patterns and pattern languages in HCI. Among the four areas that should be prioritized in future research, according to the paper's authors, is improving the production of pattern languages: "exploring and improving the processes by which patterns are identified, recorded and reviewed so that the existing stock of patterns and pattern languages available in HCI can be constantly improved and enlarged, in particular to include generic patterns as well as those focused on particular platforms or interaction styles" [28]. The framework proposed in Section 6 is an attempt to address the research topic proposed by these authors.

Complementary to the work of Dearden and Finley, Kruschitz and Hitz contribute two other surveys on HCI patterns [53, 55]. In the first one, the authors analyze the structure of HCI design patterns from 21 different pattern resources. The authors highlight the great variety of pattern structures found across repositories stating that "there exists a vast amount of patterns written by many different authors, published in web repositories, in scientific papers, and books, (...) this causes the form or structure of the patterns to vary according to the authors' preferences" [53]. Among other results, Section 5.6 presents an updated perspective on the pattern structure diversity. In their second study, Kruschitz and Hitz expand the previous research to include history, organization, validation, and tools related to patterns in HCI [55]. Although similar in content, none of the secondary studies analyzed in this section are based on a systematic approach such as the literature mapping presented in Sections 4 and 5.

4 Research Method

In order to obtain a broad view of design patterns in the context of HCI primary studies, we chose to conduct a systematic mapping, which is a particular type of systematic review. In systematic mappings, research questions are usually broader and more numerous than in systematic reviews, because the focus is to provide an overview of a research area to assess the quantity of evidence existing on a topic of interest [51]. In addition to describing the research field, a systematic mapping can also identify gaps in research literature and provide the basis for an informed decision about whether to undertake an in-depth review and synthesis on all studies or just on a subset [41].

Regarding the weaknesses of the chosen method, systematic mappings lack the synthesis and analysis of more considered approaches and studies may be characterized at a broad descriptive level and thus oversimplify the picture or mask considerable heterogeneity [41]. In the case of the conducted systematic mapping, we identified a missing structured approach for HCI patterns development, which

motivated us to deepen the discussion and propose the framework on Section 6. With this further discussion we were able to take advantage on the strengths of the method (broad view and identifying gaps) while partially overcoming its weaknesses (oversimplification).

We performed a systematic mapping considering the guidelines provided in the work of Fernandez et al. [33], Petersen et al. [77], and Kitchenham et al. [51]. The following activities were performed to define the mapping protocol: establishment of the research questions, definition of the search strategy, determination of the selection strategy, and definition of the data extraction and synthesis methods. No strategy was defined to assess the quality of the selected papers, since quality assessment is more essential in systematic reviews and often considered unnecessary for systematic mappings, which tend to be broader in scope [77]. To date, the review protocol has not been registered in any repository, but we describe each of its items in details in the following sections. The results of the mapping are presented in Section 5.

4.1 Research Questions

The goal of our mapping is to obtain a broad view of studies involving design patterns and pattern languages in the context of human-computer interaction. To achieve this goal, we defined the following set of research questions (RQ):

- **RQ1**: What are the terms most frequently used by the HCI community to refer to design patterns?
- **RQ2**: What pattern libraries are used more frequently to develop HCI patterns research?
- **RQ3**: How often are new patterns or pattern languages being proposed?
- **RQ4**: What are the research methods used in HCI patterns studies?
- **RQ5**: What standards are used for representing the structure of patterns?
- **RQ6**: In which application domains are interaction patterns being applied?

4.2 Search Strategy

In order to obtain the view of HCI researchers on design patterns, we chose six representative HCI conference series to integrate the mapping. ACM CHI Conference was an obvious choice since it is considered the main international conference of the area. The other five conferences each represent a continent: Australian Conference on Human-Computer Interaction (Oceania), Brazilian Symposium on Human Factors in Computing Systems (South America), Nordic Conference on Human-Computer Interaction (Europe), Indian Conference on Human-Computer Interaction (Asia), and African Human-Computer Interaction Conference (Africa). Because most CHI editions are held in North America and usually receive a strong participation of researchers from that region, no extra conference was added to represent this continent specifically. All the six conference series are sponsored by, organized by, or organized in-cooperation with the ACM Special Interest Group on Computer-Human Interaction (SIGCHI). Table 1 displays more details about the selected conferences.

Table 1. The six HCI conferences selected for the systematic mapping.

Region	Acronym	Conference name	First ed.	Editions
worldwide	CHI	ACM Conference on Human Factors in Computing Systems	1982	39
Oceania	OzCHI	Australian Conference on Human Computer Interaction	1989	32
South America	IHC	Brazilian Symposium on Human Factors in Computing Systems	1998	19
Europe	NordiCHI	Nordic Conference on Human-Computer Interaction	2000	11
Asia	IndiaHCI	Indian Conference on Human-Computer Interaction	2004	11
Africa	AfriCHI	African Human-Computer Interaction Conference	2016	2

We knew in advance that our choice of venues/conferences to be included in the review would have an important impact on the results. The limitations associated with that choice are better discussed on the Conclusion (Section 7) together with other limitations of the study. Among the motivations to restrict the venues to these six conferences, we can mention:

- **Restrict the analysis to HCI and HCI researchers:** patterns are a concept widely used in many research areas, frequently with varying nomenclature. In a similar manner, HCI is a very broad and multidisciplinary area within Computing. To find the intersection between the two topics may not be a trivial task. By restricting the venues to HCI conferences, we managed to capture the particular perspective of HCI researchers on the topic.
- **Include the perspectives of diverse scientific communities:** by choosing one conference from each continent, we were able to obtain the perspectives of international communities and draw comparisons (see Section 5.1).
- **Keeping the selection at high quality standards:** because literature mappings tend to be wide-ranging in scope, restricting our choice only to conferences approved by the ACM SIGCHI helped us to guarantee a good average quality of the selected papers.

The majority of the proceedings is available in the ACM Digital Library (DL)[3], the main database used for the mapping. The 1998 edition of OzCHI is available in the IEEE Xplore[4] database. Editions of OzCHI from 1991 to 1996 and from 2001 to 2004 are indexed in HCI Bibliography[5]. Proceedings from some older editions of specific events were found through manual search (event websites, personal archives, etc.). Other editions of the conferences were not included in the mapping

[3] https://dl.acm.org/

[4] https://ieeexplore.ieee.org/

[5] http://hcibib.org/

because their proceedings were not available online and could not be found timely[6]. It is worth noting that HCI papers involving patterns were rare prior to the year 2000, therefore the possibility of missing matches in the older editions of the conferences was small.

Regarding the construction of the search strings, Kitchenham et al. recommend the adoption of the Population, Intervention, Comparison, and Outcome (PICO) criteria [51]. For systematic mappings, usually only Population and Intervention are considered [51], hence no keywords were defined for the last two criteria (Comparison and Outcome). Besides that, because the review was restricted to HCI conferences, no keywords were necessary to restrict the results to papers related to HCI research (Population). The search string was then structured to restrict the papers to studies related to patterns and pattern languages (Intervention).

All the significant terms that could be related to the topic were added to the search string: *pattern(s)*, *design pattern(s)*, *pattern language(s)*, *interaction pattern(s)*, *HCI pattern(s)*, *interface pattern(s)*, *user interface pattern(s)*, *user interface design pattern(s) (UIDP)*, *cooperative pattern(s)*, *collaborative pattern(s)*, and *pattern approach*. Considering that the single word *pattern* is widely used in many different contexts, this isolated term was searched only within the titles of the papers to avoid an impractically big result set. The remaining terms were sought after in titles, abstracts, and author keywords. In the end of the process, search strings were built according to the ACM DL and the IEEE Xplore syntaxes. Because the IHC conference series also accepts submissions written in Portuguese, a translated version of the keywords was also used for this conference. For the sake of brevity, the search string is omitted in this paper.

The search consisted in applying the search string to both databases (ACM DL and IEEE Xplore). To restrict the search to the target conferences, filtering mechanisms of the engines were used. ADM DL, for example, allows one to perform a search only within the proceedings of a certain conference. The automatic search was then executed for each one of the conference series (no time period constraint was imposed). Next, the results were consolidated in a single list containing all the papers' basic information and metadata (title, authors, abstract, etc.), which served as the basic input for the selection stage.

For the proceedings not indexed in the databases, a manual search had to be performed. Early editions of OzCHI, for example, were scrutinized from the HCI Bibliography archives. Accordingly, the first editions of IHC were examined directly from the digital proceedings. Whenever the search for keywords had to be performed manually by a researcher, it was executed together with the first step of the selection strategy (title and abstract reading). The remaining papers from this manual search/selection procedure were then grouped with the papers from the automatic search for the final step of the selection stage (full reading). The only specialized tool used during the search process was Mendeley for Mac v1.19.4. Section 4.3 describes the strategies to select the resulting papers and to extract and synthesize the obtained data.

[6] Editions not included in the mapping: OzCHI '89, '90, '99, '00; IHC '98; and IndiaHCI '04, '10, '12, '13.

4.3 Strategies for Selection, Data Extraction, and Data Synthesis

In order to select the papers, a list of inclusion and exclusion criteria was defined. Table 2 shows a summary of the search and selection strategies including all the selection criteria. After the automatic and manual searches were executed, the selection was planned to proceed in two steps: a first round eliminating papers by reading the title and the abstract; and a second round performing a full read of the remaining papers. Both steps were executed by one of the authors, whereas dubious cases were discussed together by both authors and resolved by consensus.

Table 2. Summary of the search and selection strategies for the mapping.

Conferences	CHI, OzCHI, IHC, NordiCHI, IndiaHCI, AfriCHI
Databases	ACM DL, IEEE Xplore, HCI Bibliography, manual search
Inclusion criteria	Related to patterns and interaction design Primary study Written in English or Portuguese With full text available Peer-reviewed In full or short paper format
Exclusion criteria	Papers employing a vague definition of patterns without references to any prior studies on the topic

Once defined the selection strategy, we planned the extraction of data relevant to the research questions. We adopted the method of thematic synthesis [90] for the analysis of the primary studies and synthesis of the results. This approach is a variation of thematic analysis [19] adapted by Thomas and Harden for use in systematic reviews [90]. Sets of expected answers (themes) were defined for each question and an extraction form was created using a spreadsheet. Themes were identified in the papers by means of text coding, according to the approach of thematic synthesis. The details of the data extraction and synthesis procedure are described in the next section.

4.4 Search Conduction

The search protocol was executed by performing the automatic and manual searches for each conference. ACM DL has a filtering mechanism that allows searching papers from a specific conference, which facilitated the job. At first, a selection based on title and abstract was performed, allowing us to exclude papers that did not abide by the inclusion criteria. A full read of the remaining papers was then performed resulting in a total of 50 papers selected for inclusion in the final mapping. Both steps of the selection were executed by one author, resorting on the second one for solving the ambiguous cases.

All selected papers were then inspected by one of the authors under the supervision of the other one, an experienced HCI researcher. Initially the texts were coded line-by-line with codes identifying content relevant to the research questions. In a second step, codes were compared, and grouped together, whereas new codes were created as needed. Finally, the extraction form was filled

accordingly for each paper. The obtained results were then tabulated in such a way that similarities and differences between the studies could be highlighted. Finally, results were synthesized and consolidated in tables and charts for presentation. Section 5 presents a summary of the research findings.

5 Results

This section presents the results obtained from the performed systematic mapping. After a brief introduction, we make considerations on the geographic distribution and regional aspects of the papers. Subsequently, data and observations regarding each of the research questions are presented.

A total of 50 papers made it into the final list: 27 papers from CHI (54%) and 23 papers from the regional conferences (46%). Regarding paper formats and tracks, 29 papers (58%) were published in full format in the main track of the conference, while the remaining 21 papers (42%) were published in short format and/or in secondary tracks such as *alt.chi*, *Work-in-Progress*, or *Late-Breaking Work*. Table 3 shows references to all the 50 papers classified by the conference series in which they were published.

Table 3. References to all the 50 papers selected for the systematic mapping.

Conference	Selected papers
CHI	[7] [10] [20] [22] [24] [29] [30] [31] [36] [38] [39] [50] [52] [59] [61] [62] [66] [67] [70] [71] [76] [83] [87] [88] [98] [99] [104]
OzCHI	[1] [8] [60] [64]
IHC	[4] [21] [26] [27] [32] [37] [68] [69] [89]
NordiCHI	[9] [54] [75] [94] [101]
IndiaHCI	[5] [6] [47] [48]
AfriCHI	[12]

Papers were also classified according to the level of importance of patterns to the studies. Three general categories were identified and the papers were classified accordingly. The first category of papers includes studies that **propose a new pattern, pattern collection, or pattern language** as one of the main contributions. A total of 25 papers were included in this category. The second category encompasses **research about a preexisting pattern language and/or about patterns usage in HCI**. This category comprised 18 papers. Finally, one last category was defined for papers that **do not account patterns as their main research topic**, but rather use them as a device in the context of a broader study. Seven papers were classified in this latter category.

Regarding the distribution of the selected papers along the years, it is possible to observe that patterns research took a while to achieve publication status among the HCI community (see Fig. 3). From 1997, the year of the first workshop on CHI, to 2005, only five papers were published. The year of 2005 was also the last year with no publications related to design patterns in the selected conferences. Since 2006, at least one paper on the topic is published every year and there was a peak of six papers in 2014.

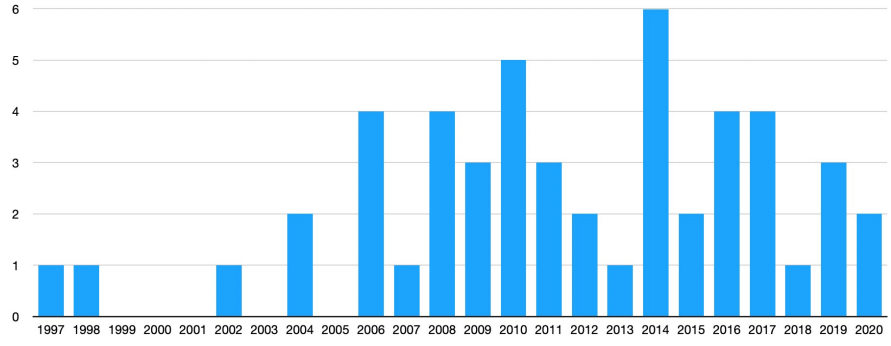

Fig.3. Distribution of the selected papers over the years since 1997.

5.1 Geographic Distribution and Regional Aspects

One of the motivations for choosing six conference series to be included in the mapping, each one based on a different continent, was to observe regional aspects among the papers. This observation was partially compromised by the relatively small number of papers related to patterns in some conferences. Nevertheless, some considerations can still be made regarding the geographic distribution and regional aspects of the studies.

Among the regional conferences, IHC from Brazil deserves a highlight as the conference with the biggest number of selected papers: nine. Four papers from the South American conference are written in Brazilian Portuguese [4, 26, 32, 69], while all other papers from the mapping are written in English. On the other side, AfriCHI, the youngest of the conferences, with just two indexed editions so far, contributed with only one paper. It is worth noticing that IHC is the only one of the conferences that accepts papers written in languages other than English (in this case, Portuguese). Given the relevance of Brazil and of the IHC conference for the South American HCI community, we opted for allowing papers in that language too.

Some peculiarities can be observed among the papers from the regional conferences. From the Brazilian conference (IHC), for example, come the two proposals to expand the concept of patterns with HCI adaptations [4, 69]. The IndiaHCI conference, in turn, contribute four papers with a common topic (touch point ecosystems and service design patterns) and a similar set of authors, all linked to the Industrial Design Center of the Indian Institute of Technology Bombay. A singularity noted for NordiCHI, is that it presents the only authors that published in CHI, as well as in a regional conference: Christian Kruschitz [52, 54]; and Gökçe Elif Baykal, Eva Eriksson, Olof Torgersson, and Staffan Bjork [9, 10].

We also analyzed the origin of papers about patterns published in the internationally renowned CHI. Out of the 27 papers published in this conference, 13 are from European authors, 12 are from North American authors (11 from the United States and one from Canada), and only two are from Asian researchers (both from Singapore). None of the papers selected from CHI came either from Latin American or African research groups. It is also worth of notice the biggest amount of pattern collection/language proposals published in CHI (17 papers) in comparison to the ones coming from the regional conferences (8 papers).

5.2 HCI Patterns Terminology (RQ1)

In order to define a common terminology for design patterns in the HCI area, terms related to the topic were searched within the selected papers. The term *pattern*, as defined by Alexander, is omnipresent and extensively used throughout the 50 papers. The longer form *design pattern* is generally seen as a synonym to *pattern* and was found in 37 of the papers (74%). In this paper, the terms *pattern* and *design pattern* are used interchangeably to designate the pattern concept as defined by Alexander. The related terms *anti-pattern* and *dark pattern* were found in three [32, 75, 101] and one paper [101] respectively. Table 4 shows a proposed terminology for the description of design patterns in the context of HCI.

When referring to patterns specific to interaction design, ten papers present the terms *interaction design patterns* and/or the shorter form *interaction patterns*. The term *social interaction pattern* is present in two papers [31, 67] referring to a different concept (human-to-human social interactions not necessarily involving a computing system) and should not be confused with *interaction patterns* meaning patterns in the context of interaction design. Terms such as *human-computer interaction design patterns*, *HCI design patterns*, and *HCI patterns* are used in five papers and help to avoid ambiguity. The terms *user experience patterns* and *UX patterns* appear in one paper representing patterns in the related field of User Experience Design. Regarding patterns specific to the design of user interfaces (UI), eight papers present one or more of these similar terms: *user interface design patterns*, *UI design patterns*, *UIDP*, *UI patterns*, *interface design patterns*, and *interface patterns*.

Table 4. Proposed terminology for design patterns based on the most frequent terms found in the systematic mapping.

Term	Description	Occur.
design pattern	General and reusable solution to a commonly occurring problem	35
anti-pattern	Ineffective approach to solve recurring problems	3
interaction pattern	Pattern related to interaction design	10
HCI pattern	Pattern used in the context of HCI	5
pattern collection	Simple set of patterns	13
pattern language	Organized set of interrelated patterns	21
pattern library	Publicly available pattern collection	4
pattern repository	Digital medium for storing pattern descriptions	2
pre-pattern	Early conventions in a specific domain	2
task pattern	High-level pattern describing user tasks	2
cooperative design pattern	Pattern related to user cooperation	3
game design pattern	Pattern related to game design	4
pattern identification	The process of eliciting patterns from a domain	15
pattern validation	The process of validating patterns	6

The term *pattern language* was found in 21 papers (42%), meaning an organized and interrelated set of patterns. The terms *pattern collection* and *pattern catalogue* are used in 13 (26%) and 3 (6%) papers respectively, usually referring

to a simpler set of patterns without any apparent organization or classification. Occasionally, the terms *pattern language*, *pattern collection*, and *pattern catalogue* were used interchangeably meaning a set of patterns. When the authors refer to pattern collections which are publicly available and are easily accessible through a website the preferred term is *pattern library*, used in 4 (8%) papers. A *pattern repository* is referred in two papers as a mean for storing pattern descriptions [48, 83]. Other combinations involving the term *pattern* were found in the following situations:

- To indicate the **level of confidence** of the patterns: *inspirational patterns* [67], *pre-patterns* [48, 104], *expert pattern* [50], etc.
- To indicate the **level of abstraction** of the patterns: *micro-patterns* [47, 88], *low-level patterns* [6, 66], *task patterns* [27, 68], etc.
- And to denote patterns of **specific domains**: *game design patterns* [9, 10, 22, 31, 39], *cooperative design patterns* [31, 38, 39], *mobile interaction patterns* [12], etc.

More general terms are clearly well established, such as *design pattern*, *pattern collection*, and *pattern language*. For patterns used in the HCI context, *interaction pattern* is the preferred option, whereas its more specific form *HCI pattern* is also recommended when there is risk of ambiguity. Regarding the pattern discovery process, papers were scrutinized for terms related to pattern identification and pattern validation. Twenty-seven papers mention at least one term for the task of identifying a pattern and a total of 24 terms have been found to designate this task. The most frequently found terms are (no. of occurrences): *identify/identification* (15), *develop/development* (13), *create/creation* (5), *discover/discovery* (5), and *generate/generation* (5). In contrast, only nine papers contain terms related to pattern validation. The terms found for nominating this task were: *validate/validation* (6), *evaluate/evaluation* (3), and *assess/assessment* (1).

5.3 Pattern Libraries Usage (RQ2)

A total of 13 papers use at least one preexisting pattern library as part of the research. This excludes papers that only cite some collection but do not present any form of usage. These 13 papers mention 11 different pattern libraries that are summarized in Table 5.

Table 5. The eleven pattern libraries mentioned by the papers.

Library name	Domain	Ref.	Mentioned by
Khambete 2013	Service Design	[46]	[5, 6, 48]
Rocha 2008	Cooperative Games	[80]	[31, 39]
Welie.com	HCI Design	[95]	[68, 87]
Yahoo! Design Pattern Library	Web Design	n/a	[68, 98]
Gameplay Design Patterns	Game Design	[13]	[9, 10]
Cheng 2015	Brain Injury Therapy Games	[23]	[22]

Common Ground	HCI Design	[91]	[87]
El-Nasr 2010	Cooperative Games	[31]	[39]
Little Springs Mobile UI Patterns	Mobile UI	n/a	[68]
Nebeling 2016	Cross-device Interaction	[71]	[70]
The Design of Sites	Web Design	[93]	[59]

Among the 11 mentioned collections, four are the results of previous studies by the same authors of the papers (Khambete 2013, Gameplay Design Patterns Collection, Cheng 2015, and Nebeling 2016). Three collections are results from other authors recorded in articles and/or books (Rocha 2008, El-Nasr 2010, and The Design of Sites). The remaining four collections were libraries once publicly available in the form of websites, from which only two remain online (Common Ground and Welie.com).

5.4 Proposal of New Pattern Languages (RQ3)

The survey revealed a total of 25 pattern collections/languages proposed by the authors. The description of the patterns in these papers assumed a variety of different forms, indicating a lack of standardization for this task among HCI researchers.

In five of the papers that propose new collections/languages, the total amount of patterns that compose the final set is not stated clearly [12, 20, 47, 60, 104]. In these cases, it was common to present a few patterns as examples. From the 20 papers that make explicit the number of new patterns identified, two provide only one pattern as the result of the research [8, 24]. In contrast, the largest language contained a total of 53 patterns [88]. The remaining 17 collections/languages presented an average of 14 patterns.

Only ten papers include a complete description of the language within the text. This is particularly the case for smaller languages: the biggest fully described language contains 13 patterns. Among the papers that do not include complete language descriptions, five offer a link on the Web to access the complete listing [7, 66, 68, 75, 88]. By the time of this writing, however, only one of those links [88] was still active.

5.5 Research Methods for HCI Patterns Studies (RQ4)

The papers selected for the mapping were also analyzed regarding the scientific methods used to elicit and/or study HCI patterns. As stated before, 25 papers propose a **pattern collection/language as one of the main contributions**. Special attention was devoted to the methods used to identify and validate these proposed pattern collections/languages (see Fig. 4 for a summary of these methods). Before delving into this topic, we analyze papers that do not propose any new pattern or language.

Eighteen papers describe **studies about patterns in HCI** without proposing a new language definition as the main contribution. Four of these papers describe field studies [1, 5, 6, 47] while four other papers present prototype evaluations [10, 23, 38, 70] to examine some aspect or specific utilization of patterns in an HCI context. In another three papers, researchers use literature reviews, surveys, and/or

interviews to delineate HCI patterns usage [52, 54, 76]. Case studies involving patterns are described in three papers [87, 98, 101]. An exploratory research [61] and a virtual ethnography [21] are reported in one paper each. Finally, two papers propose expansions to the concept of pattern in an attempt to adapt it to HCI [4, 69].

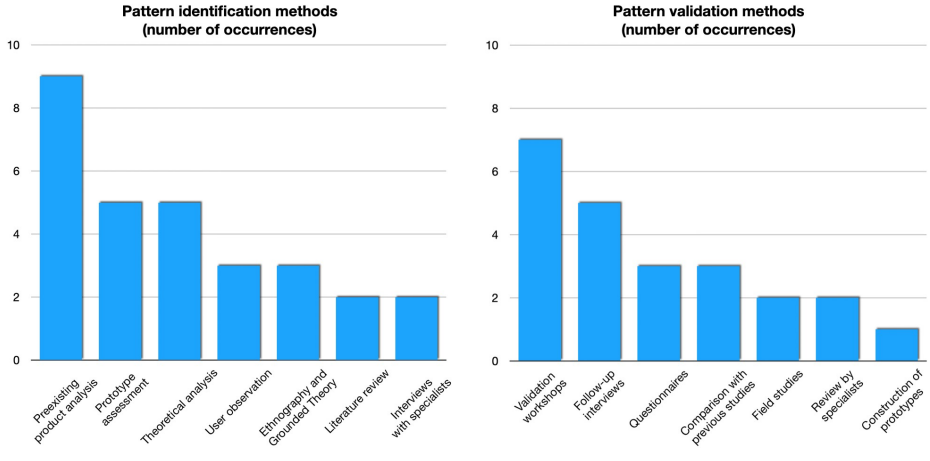

Fig.4. The most frequently used methods for HCI patterns identification and validation.

Another seven papers present some usage of a pattern or **pattern collection/language as an auxiliary device in the context of a broader research**. In four of these papers, authors propose the usage of patterns to improve some stage of the software development process [26, 27, 32, 89]. In the other three papers of this category, researchers employ patterns in the development or evaluation of some prototype tool [9, 59, 64].

A total of 26 papers contain descriptions of some **pattern identification** process, even if a pattern or pattern language is not the main contribution of the study. A variety of pattern mining methods is reported and it was not uncommon to find mixed method approaches. Nine of these papers mention the analysis of preexisting products/systems by specialists to identify patterns. The quantity of investigated systems amounted from 14 [31] to hundreds [24], but usually remained around a few dozens of examples. Another five papers reported the assessment of prototypes to elicit patterns [7, 39, 75, 83, 104]. The observation of final users was reported by three papers as the main approach [39, 71, 83]. Two papers mention literature review as a source of patterns [12, 88], while five other papers mention theoretical analysis as the main method [8, 20, 36, 47, 60]. Ethnography and/or Grounded Theory was reported by another three papers [29, 30, 62], and two papers describe the use of interviews with specialists and/or final users as one of the methods for pattern identification [12, 66]. Other methods cited include the application of a questionnaire [83] and a claims-to-patterns approach[7] [12].

[7] Belay et al. propose a framework in which patterns (contextualized design guidance) are derived from claims (falsifiable hypotheses) [12].

Most of the 26 papers that describe some identification process do not mention the minimum number of occurrences necessary to characterize a pattern, the only exceptions being three papers that report two [62], three [99], and "more than three" occurrences [68] as the minimum number. It is also worth mentioning that 12 papers reported some byproduct from the pattern elicitation procedure. In eight of these papers, this further contribution is a methodology/framework aimed at improving the design process [7, 12, 24, 29, 31, 47, 98, 104], while the remaining four papers present a prototype or tool designed with the aid of the patterns [22, 37, 50, 83].

Some sort of **pattern validation** is described in a total of 18 papers. The most commonly reported validation method was the conduction of workshops, sometimes called design sessions, gathering HCI specialists and designers. This form of evaluation is reported by seven of the papers. One paper does not cite the number of participants in the workshops [99], and another one presents the unusually big number of 23 participants [7]. The remaining five papers report an average of 5.5 participants in the workshops. Regarding the type of the participants, five of the papers cite workshops attended by specialists, including designers, engineers, HCI experts, and software developers [29, 59, 66, 83, 99]. In the other two studies, workshops were composed by technology students [7, 75]. Field studies with random users were the chosen assessment method in two papers [24, 50]. In three other papers researchers compared the obtained pattern language with results from previous studies to validate the patterns [30, 62, 88]. Three papers mention the use of questionnaires [7, 59, 99], and five papers mention the use of follow-up interviews [23, 24, 29, 50, 83] as complementary methods to evaluate the patterns. Other mentioned validation methods include: the review of the patterns by independent specialists [23, 31]; the parallel identification of patterns by independent specialists with subsequent comparison [31]; and the construction of prototypes using the patterns [37].

Using **cards** during the process of pattern identification and validation was reported in five papers [6, 7, 48, 67, 99]. In general, cards were used to display a visual representation of the patterns to specialists and workshops' participants. Another paper cited the use of posters on the walls with a similar objective [29]. A summary of the pattern description including at least one example image is usually the content printed on each card. Athvankar et al. propose the following attributes to be included in the cards: in the front, name, summary, and connected patterns; and, in the back, examples with images [6].

5.6 HCI Patterns Structure (RQ5)

Besides the 25 papers that propose new pattern languages, another three papers also describe some pattern structure used during the research, totaling 28 papers that present some set of attributes used to define a pattern. Seventeen of these papers do not mention any pattern standard used to structure the patterns. The remaining 11 papers cite a total of 8 standards. The Alexandrian Format [2] is the most common standard, mentioned in five papers [20, 29, 47, 59, 67]. The Borchers format [16] is the inspiration in two papers [75, 88], the same number that mention PLML [35] as the preferred format [4, 68]. The Human-Artifact Model defined by Bodker and Klokmose [14] is mentioned by one paper as a source of inspiration

[88]. Other cited formats include previous studies by the same authors [62, 66] and well-known pattern libraries such as Welie.com and The Design of Sites [59, 75].

It is worth highlighting the general lack of standardization in pattern structure considering the analyzed HCI papers. At least 30 different attributes were found and their presence in pattern descriptions varied both in quantity and nomenclature. Table 6 shows a summary of the main attributes used to describe patterns in the context of HCI.

From the number of occurrences seen in Table 6, we can identify a core set of attributes used more frequently: *name* (28), *solution* (27), *problem* (14), *examples* (14), and *context* (11). A second set of attributes is found in a smaller number of papers, but is still frequent: *illustration* (8), *forces* (8), *synopsis* (6), *related patterns* (6), *rationale* (6), and *diagram* (4). Some other attributes that are suggested by the standards are seldom used: *number* (3), *alias* (1), and *implementation* (1). Finally, there are attributes mentioned in the pattern standards that were never used in the analyzed papers: *confidence*/*ranking*, *literature*, and *management information*.

Another common practice among HCI researchers was to include into pattern descriptions some domain specific attributes. Bach et al., for example, include *comic layout* and *comic content relation* in their design patterns for data comics [7]. *Narrative role* and *timeline* are the attributes added by Kim et al. in their storytelling patterns [50]. Similarly, Cheng and Putnam assign *associated therapeutic goals* to their patterns of games for brain injury therapy [23].

Table 6. Pattern attributes: their presence in established standards and number of occurrences in the literature mapping.

Attribute	Aliases	Alexander	Borchers	PLML	Occur.
number	id	✓			3
name	title	✓	✓	✓	28
illustration	picture, photos	✓	✓	✓	8
context	scenario, background	✓	✓	✓	11
synopsis	what, summary, intent	✓		✓	6
problem		✓	✓	✓	14
solution	how, description	✓	✓	✓	27
diagram		✓	✓	✓	4
relationships	references	✓	✓	✓	6
confidence	ranking	✓	✓	✓	0
forces			✓	✓	8
examples	evidence		✓	✓	14
rationale	why, motivation			✓	6
alias				✓	1
implementation				✓	1
literature				✓	0
management				✓	0

Two other papers contain explicit proposals to extend the concept of design patterns adapting it to an HCI context. Aquino et al. propose the inclusion of layers indexed by *personas* to express users' diversity in patterns [4]. Moreira and Pimenta, in turn, propose *concrete interaction patterns* (CIPs) to describe interactions and user interface behavior through the User Interface Description Language (UIDL) [69].

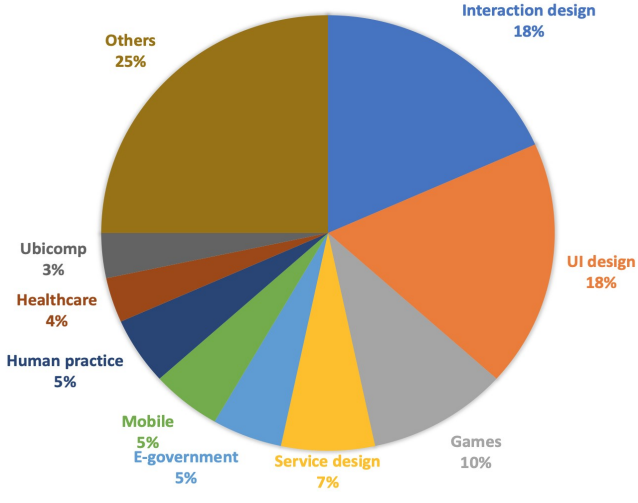

Fig.5. Application domains of the papers in the literature mapping.

5.7 Application Domains (RQ6)

In order to discover in which application domains and HCI subareas are interaction patterns being applied, each paper in the mapping was associated with one or two domains. Sometimes the study investigated patterns in more than one context, hence why some papers were associated with two domains. A total of 60 mentions were found, comprising 24 different domains. Fig. 5 shows the distribution of application domains found during the mapping.

The majority of the papers present generic studies on patterns usage in HCI therefore their characterization as pertaining to the *interaction design* or to the *UI design* domains. *Games*, *service design*, *e-government*, *mobile*, *human practice*, *healthcare*, and *ubiquitous computing* complete the list of most frequent application domains.

6 An HCI Patterns Development Framework

A further analysis of the findings from the systematic mapping motivated the proposal of a framework for HCI patterns development. Throughout the history of design patterns, especially among the software community, there have been some attempts to detail the process of developing pattern languages. Nonetheless, we could not find a satisfactorily complete description of this process specific to patterns in an HCI context.

A first attempt to define the process of identifying patterns, or at least to propose its fundamental aspects, can be found in *The Timeless Way of Building* by Alexander [3]. The book is written in an almost poetic form and starts by defining what Alexander calls *the quality without a name* (QWAN) and the search for it. According to Alexander, QWAN is a certain good quality that you can recognize when you see it, but which is difficult to describe in words. More recently, Salingaros published a review on the ideas of Alexander describing in a more organized way the development, validation, and evolution of patterns in the field of Architecture [82].

When patterns aroused the interest of software engineers in the early nineties, more structured attempts to define the pattern development process emerged. In 1994, the first Pattern Languages of Programs (PLoP) conference took place, gathering software patterns enthusiasts and establishing the basis of a pattern language discovery process in that area. Methods such as *shepherding* [44], *writers' workshops* [25], and *pattern writing* [65] became common practice among attendees of the annual conference and were themselves described in detail through the use of pattern languages. In addition to the identification of patterns, the pattern evaluation process also received attention from researchers, which proposed diverse criteria for pattern assessment [49, 78, 103]. Finally, more general analysis regarding the usage of case studies [102] and a comparison between inductive and deductive methods for eliciting patterns [84] can also be found in the literature.

As patterns became more popular, proposals for pattern identification processes emerged among researchers from other computing related areas such as E-learning [79] and Human-Computer Interaction [45, 100]. None of these methodologies, however, cover the entire pattern development process as the framework we describe in this paper. Many of the aspects mentioned by these authors are explored in more details in the discussion of the proposed framework. It is also worth mentioning that the studies more focused on the pattern development process are either not based on an HCI context [82] or emphasize a pattern mining method leaving out other stages of the pattern development [45, 79].

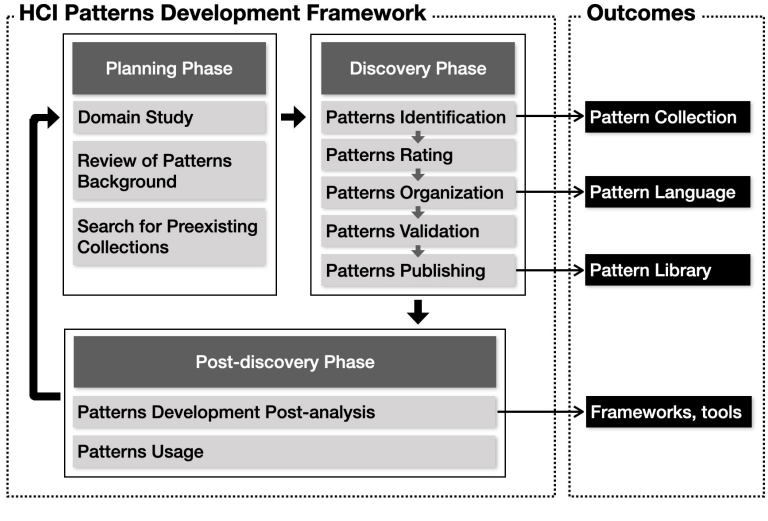

Fig.6. A framework for design patterns development in HCI.

The framework construction was based on the described literature mapping and on the studies mentioned previously on this section. By doing this, we were able to relate the framework to the way methods are being applied among the HCI community as well as to identify aspects that could be improved in the current practices. The analysis of the aforementioned papers allowed us to identify stages and outcomes that are typical to the patterns development process in HCI. The organization of these stages in a pattern life cycle form the basis of the proposed framework seen in Fig. 6. Stages pertaining to the framework were grouped into three main phases, namely: *Planning Phase*, *Discovery Phase*, and *Post-discovery Phase*.

A typical pattern development process will include the *Patterns Identification* and some of the other stages, but not necessarily all of them. Stages in the Planning and Post-discovery phases can be executed in any order, while the steps of the Discovery phase depend on outcomes from previous stages and work better when executed sequentially. The sequence of the three phases is strict and should follow the indicative arrows completing the development cycle.

The iterative configuration of the framework expresses the notion that a pattern language is not always static. On the contrary, whenever the language elicited in the Discovery phase is practical and alive, it will most probably be constantly evolving. Living pattern languages should be continuously updated in such a way that the observations from the Post-discovery phase feed the Planning phase initiating a new development cycle. The following sections describe each of these phases in more details.

6.1 Planning Phase

Any process of pattern language development starts with an initial phase of planning. The stages involved in this phase include a study of the domain, a review of pattern theory, and a search for preexisting pattern collections. Each one of these stages is described in the following sections.

Domain Study The first step in a pattern development process is usually studying the domain of the pattern language. As stated before, developing pattern languages is considered a complex and laborious task, hence the necessity to acquire a deep knowledge in the domain area prior to start searching for patterns. Even if the language writers are specialists in the domain being investigated, some sort of study is usually performed.

Activities related to domain study are described in many papers of our systematic mapping, indicating that it is common practice among HCI pattern developers. In some cases, exploratory research is reported as a mean of enumerating products and/or systems in that specific domain that shall serve as evidence for the pattern discovery. According to Wania and Atwood, the information retrieval (IR) systems used in their research were chosen “by first examining all the IR systems available through Drexel University’s library” [99]. Mitchell and Boer, in turn, report that their inspirational social ice-breaking patterns “originate from an ongoing large-scale design space review of design, art and other experimentation” [67]. In other cases, an extensive literature review is performed to unveil subtle aspects of the domain. Zimmerman, for instance, reports

a "research on product attachment and how this leads to the philosophical stance of designing for the self" as a step to reach his patterns related to Product Attachment Theory [104].

Review of Patterns Background Another typical step of the Planning phase is to perform a review of pattern literature. As we have seen throughout this paper, there is great variety in pattern formats and methods, and the best strategy to follow may not always be obvious. Sometimes, researchers in charge of the pattern development are specialists in their area but have little experience with pattern methods. In other cases, developers will feel the necessity to deepen their knowledge on patterns, in order to choose the most appropriate approach. This is the moment when the research team will decide the pattern format to use, the methods used for pattern identification and validation, and the medium in which the pattern language is going to be published. Although some concepts are fundamental and frequently cited, such as the work of Alexander, there is no rule of thumb, and each situation may require a different solution.

Many of the papers inspected for the mapping present a section describing the pattern background used as a reference. In their ethnographic study on patterns for front line firefighting, Denef et al. state that "the research is guided by the works of Erickson, McCullough, and Crabtree in their interpretation of Alexander's work to understand the configuration of environments and to guide (...) design by means of patterns of events derived from ethnographic data" [30]. A detailed section devoted to pattern theory can also be found in the work of Flores et al. discussing "the use of patterns in interaction design and musical interaction design, presenting motivations, an overview of the main concepts and background on the subject" [37]. El-Nasr et al., on the other hand, focus their review on researchers that "analyzed a set of cooperative games to develop cooperative game design patterns" in order to develop their pattern collection [31]. As can be seen in these examples, the exact sources to be researched will depend on the application domain of the study in question.

Search for Preexisting Collections A search for preexisting pattern collections and languages can be useful in the process of developing a new language in several ways. At first, searching for patterns in the same application domain may ensure that the intended language will not overlap languages obtained from previous studies. In some cases, it may be preferable to extend an existing language rather than developing a language from scratch. Finally, analyzing other collections may give hints to authors regarding the discovery of the new language.

Section 5.3 of this paper lists 11 different pattern libraries that were actively used during the HCI studies covered in the literature mapping. This indicates that the search for preexisting collections is a recurrent task among HCI researchers. Miyamaru et al. relate their task patterns for e-government with three popular UI pattern libraries and report that the authors "were not able to find a UI pattern library for iDTV in the same maturity level of the web and mobile pattern libraries" [68]. Obrist et al., in their proposal of UX patterns for audiovisual applications, also describe an extensive search for pattern languages in the HCI field and conclude that "existing attempts to focus on the user's experience are fragmentary

and lack a comprehensive pattern collection" [75]. The authors of two other papers in the mapping opted for extending existing collections instead of writing a complete new one [31, 59].

6.2 Discovery Phase

The strategy resulting from the Planning phase is used by researchers to start discovering patterns and the pattern language. The Discovery phase consists of five steps: identification, rating, organization, validation, and publishing of patterns. Each step is further discussed in the following sections.

Patterns Identification The patterns identification can be considered the main stage of the whole pattern development, to the extent that many scientific reports will only detail this part of the process. At this point, researchers apply the methods chosen in the Planning phase with the objective of eliciting one or more patterns in a particular domain. The outcome of this stage is typically a collection of patterns that can be documented and presented as is or further improved to become a pattern language and/or library.

The foundations of pattern identification were laid down by Alexander and have given rise to a multitude of discovery methods adapted to many different contexts, including HCI. Section 5.5 presents the most common methods found in our systematic mapping. In addition to that, reports from the software patterns community also register other important techniques, such as pattern writing [65], shepherding [44] and writers' workshops [25]. Shepherding happens when a pattern researcher (the *sheep*) submits his/her patterns to an experienced colleague (the *shepherd*) for feedback prior to a writers' workshop or other type of review [44]. Writers' workshops, in turn, originated in the creative literature community and consist of gatherings that follow a collection of normative behaviors designed to give authors constructive feedback on their work while protecting their dignity [25].

According to our systematic mapping, the most used method for pattern identification in HCI is the *analysis of interactive systems*: a total of nine papers report this as the main approach to discover patterns. This finding is in line with the work of Alexander and with previous studies on patterns in Software Engineering, which usually agree that patterns must be discovered by reference to design solutions [28]. It is remarkable, however, that this was not the only method used by HCI researchers. In our mapping, methods such as prototype development/assessment, theoretical analysis, observation of user tasks, ethnography, Grounded Theory, literature review, and interviews with specialists were also reported in a considerable number of papers. These results indicate that the patterns identification stage in HCI may be more diverse than in other fields, such as Software Engineering.

Besides the aforementioned mining methods, pattern writing and critiquing techniques are commonly employed by the software patterns community and resemble techniques found in HCI studies. Mirnig et al. explicitly report that each of their patterns "was written by an HCI expert with experience in pattern writing" and then give details on the content and structure of their security patterns for web

design [66]. No direct mention to shepherding was found in our HCI systematic literature mapping. Nevertheless, some reports do present procedures similar to that of shepherding. Wania and Atwood, for instance, report that their patterns were "given to 5 doctoral students who volunteered to read the 39 patterns" and that they "were revised based on the feedback of the volunteers" [99]. Regarding writers' workshops, Obrist et al. attest that they "conducted a writers' workshop with the researchers, in which the initial UX patterns were discussed and modified, and additional patterns were defined" [75]. Besides that, workshops were also frequently reported as a form of pattern validation, something we shall discuss in Section 6.2.

Patterns Rating Pattern rating refers to the activity of assessing the confidence level of a pattern. Including a confidence rating in the patterns' descriptions can be useful for pattern consumers to identify the significance and maturity of each design solution. Despite being frequently neglected, the foundations for this task can be found in pattern literature. The first reference to an assessment of the pattern level of confidence is found in *A Pattern Language*. Alexander defined a zero to two scale in which patterns were classified as follows: zero asterisks for low-confidence patterns or patterns that do not represent a true invariant solution for the problem; one asterisk for medium-confidence patterns; and two asterisks for patterns that truly reflect an invariant solution [2]. This concept is also referred by HCI researchers. In his formal description of patterns, Borchers includes an attribute called *ranking* [16] which is analogous to the attribute *confidence* present in PLML [34]. Despite the references to pattern rating in HCI pattern literature, none of the HCI pattern language descriptions found in our systematic mapping included this attribute in their pattern structure.

In order to rate a pattern according to its confidence level, we recommend the zero to two asterisk ranking defined by Alexander. The zero-asterisks is the level for incipient patterns, such as inspirational patterns and pre-patterns. Patterns with only one occurrence in the corresponding domain (or even none, in the case of inspirational patterns) can be included in this level. Based on observations of our systematic mapping, we propose at least two occurrences to classify a pattern in the one-asterisk level (medium-confidence) and at least three occurrences to classify a pattern in the three-asterisks level (high-confidence).

Patterns Organization In order to be considered a pattern language, the collection obtained in the previous steps still misses some organization. According to Alexander, "each pattern can exist in the world, only to the extent that is supported by other patterns: the larger patterns in which it is embedded, the patterns of the same size that surround it, and the smaller patterns which are embedded in it" [2]. The patterns organization is the stage in which developers elicit these relations between the patterns in the collection and unveil the network structure that characterizes a pattern language.

It is important to note that not all pattern developments will produce a complete pattern language as their output. For many papers analyzed in our systematic mapping, the main contribution of the research is only a single pattern or a small collection of patterns without any hierarchical structure. Other papers, however,

make explicit reference to the pattern organization process. Mirnig et al., for example, declare: “thanks to the internal structuring and keyword references within the patterns, we were finally able to condense the patterns into three levels of abstraction” [66]. Wania and Atwood, in turn, affirm that “as more and more patterns were discovered, the relationships between the patterns became apparent and the relationships were documented” [99]. These latter authors also describe the usage of card sorting in order to “gain an understanding of the overall structure of the language and the relationships within the language” [99]. Miyamaru et al. describe their pattern identification process as a sequence of workshops and report that “the last workshop developed relations between patterns and between them and UI libraries” [68]. For all studies that include the step of patterns organization, a complete description of the pattern language is the main output of this stage.

Patterns Validation Once a pattern language is discovered and fully described, validation procedures may be applied in order to guarantee that the language is well written and useful to the design community. *Shepherding* and *writers' workshops*, described in Section 6.2, can be viewed as forms of pattern validation, but, since they are applied in a very early stage of development, they are considered parts of the pattern identification process in this framework. This section presents other methods for pattern validation in HCI that emerged from our literature review and systematic mapping.

At first, it is reasonable to define which are the criteria used to evaluate patterns. In two papers from our systematic mapping [66, 75] researchers adopted validation criteria derived from the framework of Wurhofer et al.: *findability*, *understandability*, *helpfulness*, *empirical verification*, and *overall acceptance* [103]. These criteria are based on some previous studies, including a paper by Khazanchi et al. which defines guidelines for evaluating patterns in the Information Systems domain [49]. Petter et al., evolved these guidelines using an HCI pattern as example and proposed a different set of criteria based on design science research [78]. Based on the criteria from these three studies, we propose the following consolidated list of criteria for HCI patterns evaluation:

- **Findability:** A pattern has to be found easily and quickly within a pattern collection/language [103]
- **Effectiveness:** The pattern is stated in terms that are correct, comprehensive, complete, internally consistent, and concise [49].
- **Feasibility** The pattern description gives the user sufficient information about how to realize the pattern in practice [103]. Pattern can be operationalized [78].
- **Reliability:** The pattern should produce the same general effect each time it is applied [78]. There is empirical evidence which approves the correctness of the pattern [103].
- **Plausibility** The pattern is sensible considering the current understanding of the domain [78].

Regarding the methods for patterns validation, our systematic mapping indicates the conduction of *design workshops* as the preferred method: a total of seven papers report this as the main approach for validating patterns in HCI. In the design workshops, sometimes also called *design sessions*, participants are usually designers or other technology professionals not necessarily experienced with

patterns. The tasks performed are usually related to designing some software or other interactive product using the aid of the pattern language being evaluated. The quality of the final products is then assessed to evaluate the effectiveness of the patterns. Interviews and questionnaires are frequently applied to workshop attendees in order to gather additional information on the usage of the language. Other validation methods mentioned in the mapping include: comparison with previous studies, reviews by specialists, and field studies.

Patterns Publishing The stage of patterns publishing consists of making the patterns collection available to the public by publishing it on some sort of book or website. Pattern languages achieve their full potential when they are used in practice, discussed, and improved. Making them available to a greater audience increases the chances of this full development. Unfortunately, many proposals of new pattern languages in the area of HCI never reach that status.

Of the 25 new proposals of patterns and pattern collections found in our systematic mapping, only 10 are fully described within the papers. Five papers that do not present full descriptions of patterns include a link to a website where the complete collection should be available. Only one of these links was still active by the time of this writing [88]. Smorgun et al. refer to Semantic˘ MediaWiki[8] and Page Forms extension[9] as the tools used to collect the design patterns and to gather a range of characteristics of each pattern: “this was an important step in transitioning from a collection of interaction techniques to a catalogue of design patterns” [88]. Additional studies are required to elicit why so few HCI pattern collections remain available to the public.

6.3 Post-discovery Phase

Once the new patterns are discovered, they are ready to be used to generate artifacts in their own context. Analysis of this usage might give rise to a framework or theory. Sometimes a software tool is created in order to ease, operationalize, or validate the application of the language. Findings from the Post-discovery phase can feed back the Planning phase starting a new cycle of development.

Patterns Development Post-analysis The development of a new pattern or pattern language does not necessarily end with its discovery and publication. Patterns embody a detailed representation of a domain’s context, its problems, and common solutions. In the post-analysis stage, developers have the opportunity to analyze the newly created patterns and draw further conclusions about these factors. Frameworks, theories, or tools are some examples of byproducts yielded from the pattern development process.

A total of 12 papers included in our systematic mapping report some post-analysis of the development process. Four papers derive some sort of framework or set of guidelines from the patterns [7, 31, 47, 104]. Bach et al., for example, propose a mapping of the design space for data comics and draw out some “themes

[8] https://www.semantic-mediawiki.org

[9] https://www.semantic-mediawiki.org/wiki/Extension:Page_Forms

of particular interest for designers of data presentations" [7]. Similarly, Zimmerman clustered his patterns producing "six framing constructs, which work as specific perspectives designers can take when applying Product Attachment Theory" [104]. Another four papers contribute some improvement to the interaction design process from the analysis of the patterns' usage [12, 24, 29, 98]. Denef and Keyson, for instance, analyze the usage of their frontline firefighting pattern language and state that "it supports communication and thus an open dialog on implications for design" [29]. Finally, four papers describe tools based on the presented patterns: a human-robot social interaction design tool [83], a mobile application for video storytelling [50], a prototyping tool for game design [22], and mobile applications for musical interaction [37].

Patterns Usage The last stage of the Post-discovery phase is the usage of the pattern or pattern collection in a design project. As observed by Dearden and Finlay, patterns can be used in different ways during the development of an HCI project: enabling users to actively engage on a participatory design process; helping to support design debates as a specialist technical lexicon; serving as a tool for the management of the organizational memory and knowledge; assisting as a lingua franca in multidisciplinary projects; and providing design rationale for particular design decisions [28]. Pattern developers should monitor the forms of application of their patterns and the feedback from the users, since this information can produce valuable insights and improvement suggestions.

Although many papers from our systematic mapping describe pattern usage in evaluation experiments and controlled environments, only one paper presents an analysis of the usage of patterns in an industrial development project [87]. Segerståhl and Jokela conducted their study in a company specialized in developing heart rate monitors and software tools for athletes: the authors assessed the usability of patterns from the Common Ground and Welie.com libraries by analyzing the application of the patterns during the design of a software product [87]. With scarce and inconsistent reports on pattern usage, the utility of patterns in real projects and their popularity among professionals remain controversial topics that deserve further investigation.

7 Conclusion

Patterns and pattern languages have been attracting the attention of researchers from many different areas since their inception in the work of architect Christopher Alexander in the late 70's. Despite controversies on the practicality of patterns and the apparent low adoption rate in real projects, the topic continues to arouse the interest of the scientific community. In this work we focused on the research of patterns and pattern languages in the area of Human-Computer Interaction, presenting the results of a literature mapping that included publications from six HCI conference series from different regions of the world and yielded a framework for HCI patterns development. In this section, we present some identified limitations, a discussion on the main contributions of the paper, and opportunities for future work.

The main limitations that could threaten the validity of this paper are related to selection bias, inaccuracy in data extraction, and lack of validation of the proposed framework. Selection bias refers to the distortion of a statistical analysis due to criteria used to select publications. Choosing six HCI conferences distributed around the globe as the source of the literature mapping allowed us to obtain an overview of the research on patterns generated by the international HCI community and discuss regional aspects of the results. Nonetheless, this decision does not guarantee access to the best quality papers, since we ended up excluding important journals and other relevant conference series. A more comprehensive study, including major HCI journals and conferences, could be performed and then the results compared in order to assess the impact of this decision. It is important to highlight, however, that many related papers from these other sources were indeed reviewed and included in the discussions of Sections 3 (Related Work) and 6 (Framework). Another possible limitation of the mapping is the possibility of the information being extracted in different ways by different reviewers, which might cause inaccuracy in data extraction. For the purpose of mitigating this threat, at least partially, all 50 papers were classified and inspected by one of the authors under the supervision of an experienced HCI researcher also proficient in design patterns. Online meetings were organized to address contentious extraction decisions. Finally, we considered that applying some sort of validation to the proposed framework would be out of the scope of this study but consider this possibility as a future work.

Regarding its main contributions, this paper presents a systematic literature mapping of patterns research in HCI and a corresponding framework for HCI patterns development. Our systematic mapping of HCI patterns literature present an overview of studies conducted by HCI researchers since the topic gained momentum within this community by the end of the 90's. Secondary contributions from the mapping include: a proposed terminology for HCI patterns; a listing of pattern identification and validation methods frequently used by HCI researchers; and a summary of well-known pattern structure standards and their corresponding attributes. The findings from the systematic mapping were subsequently organized and extended in the form of an HCI pattern development framework. Based on the papers from the mapping and on other related work, our framework describes a sequence of stages organized into phases that can be followed to achieve a meaningful and practical HCI pattern language. As part of the framework, we recommend a strategy for the classification of patterns according to their level of confidence and propose a consolidated set of criteria for HCI patterns evaluation. The proposed framework can serve as a device in the development of new HCI pattern languages, stimulating scientific studies and a wider usage of design patterns in HCI.

Some future work regarding this research includes expanding the systematic literature mapping and validating the proposed framework. The paper selection for the systematic mapping could be broadened by including journals and other conferences. The impact of the newly discovered papers on the mapping results could then be evaluated and the framework revised. Other future improvement would be to validate the framework proposal by submitting it to the evaluation of specialists, for example. Developing a new pattern language following the steps of the framework could also serve as evidence of the process practicality and utility.

Finally, the development of tools based on the framework, such as a pattern repository for instance, could encourage more researchers and professionals to develop and publish their own pattern languages.

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