User Experience Design in Software and Hardware Components Studied in Human-Computer Interaction

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Abstract. User Experience (UX) is a concept based on the human-product interaction. An increase of UX studies in the Human-Computer interaction (HCI) field was observed in the last decade. Empirical studies based their experimental activity on HCI products, which are characterized by two components: Software and intangible (digital interfaces and web apps) and Hardware and physical (devices). Trough an explorative study, the authors propose a research direction to compares UX studies targeting software and hardware components of HCI products. A preliminary sample of papers was considered. The authors collected contributions where UX in HCI design is investigated through case studies involving devices with software and hardware components. Objectives, methods, and tools of each case study were compared. It emerged that complex systems require both quantitative and qualitative analysis approaches, as the wide variety of tools for data acquisition and processing show. Since Hardware components are more closely related to products such as consumer goods and engineering products, it is possible that methods and tools used to study hardware components could also be applicable to other physical and tangible products, i.e., the main reference for product, engineering, and mechanical design.

Keywords: User experience · HCI design · Software · Hardware · Tangible · Intangible

1 Introduction

The term "User Experience" (UX) was introduced by Norman [1] to extend the study of human-product interaction beyond the consideration of usability and effectiveness. Scholars attempted to find a shared definition to this concept [2–5]. Simultaneously, theoretical models on UX have also been developed over time [6, 7]. Ogunyemi et al. [8] reported a strong growth of UX studies in the last decade. Especially with the advent of new technologies, the domain of Human Computer Interaction has been established. Hassenzahl and Tracktinsky [9] noted a shift in focus within the 'analysis of the study of UX in Human Computer Interaction (HCI). At the beginning contributions focused only on programmatic and task related aspects. Gradually literature on the topic became

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more conceptual. These articles aimed at a common vision of what characterizes a good UX. These concepts have been applied in empirical studies that involved products with a software and intangible component and, a hardware and tangible component [10, 11]. The former refers to digital products such as Web Apps and digital interfaces; the latter refer to the physical part of the devices (e.g., smartphones, keyboards, and laptops).

Tests and experiments that analyze HCI products are numerous, while empirical studies that examine tangible objects such as consumer goods or engineering products are not likewise widespread or do not rely on adequate research questions [12]. The hardware component can be considered close to the world of consumer goods and engineering products. Thus, it is plausible that methods and tools used to study hardware components could also be suitable for consumer goods and any other product that involves a physical component.

Based on these considerations this work aims at investigating the UX with HCI products characterized by software and/or hardware components. Particularly, objectives, methods, instruments, and typologies of experiences in experimental research have been classified and compared.

The paper is structured as follows. Section 2 provides the selection method applied for the research of contributions, as well as the selection criteria to collect a pertinent sample of papers to be analyzed. Section 3 proposes the classification criteria in detail followed by the resulting table. Section 4 presents the discussions, while Conclusions are drawn in Sect. 5.

2 Methods of Research

To verify the presence of different UX approaches towards software and hardware components in HCI, a sample of convenience of studies should be selected.

The selection of a preliminary reference sample of studies took place by first selecting a pertinent journal of the topic. The "International Journal of Human-Computer Interaction" was considered an authoritative and pertinent source. It was chosen since it addresses, among the others, the cognitive, and ergonomic aspects of interactive computing with a particular attention to human elements related to system and contexts of interaction. The search was performed in Google Scholar, where keywords such as "user experience", "HCI", and "case study" have been used to search pertinent papers limited to articles published in the aforementioned journal. The authors considered papers presenting case studies described in contributions published between 2015 and 2021 only. From an initial sample of more than 100 papers those contributions proposing methodologies and theoretical approaches have been neglected. For brevity, only the papers including "User experience" and "case study" in the title or in the abstract have been considered. 15 articles have been collected to form this preliminary sample. This limited number of sources is clearly not exhaustive. It was nevertheless considered sufficient for extrapolating the existence of differences in UX towards hardware and software. The admitted length of the present paper represented a further constraint for the authors.

3 Classification

The articles belonging to the final sample were classified along the dimensions shown in Table 1, which provides an overview of the result of the categorization work. The most relevant classes were identified in an intuitive way upon after reading the selected contribution. The choice of the classes was also supported by other review works carried out within UX and the use of technological systems within design [13, 14]. Accordingly, contributions have been organized based on their year, source, product typology (software of hardware), objectives, methods, instruments involved in the study and typology of UX. The details of each category follow.

- The "Product" column considers the specific HCI products investigated in each study.
- HCI products have been categorized into two main groups: Software ("S") and "Hardware" ("H"). In the table, an "S" was assigned when the case study involved digital products (e.g., Web apps, websites interfaces, pop-up warnings among the others); "H" when physical products (smartphone hardware, tablet hardware, haptics systems components among the others) were analyzed. "S/H" means that both software and hardware components were considered.
- "Objectives and topic facets" have been expressed readapting the categorization made by Ogunyemi et al. [8] (table 6, p. 13–14,). Since the original categorization was general, the purpose of the adaptation was to focus on the UX domain, including the evaluation of UX and related approaches.
- "Methods" include to the theoretical approach and methodology used to acquire and collect data. Authors focused on data analysis (quantitative and/or qualitative), environment and experiment setting (natural or controlled or non-specified), and participants involved (final users and/or experts).
- "Instruments" relate to product representations presented to participants (prototype or end-use product) and the technology involved in data acquisition as support tools, such as biofeedback (biometric measurements tools such as skin conductance (SC), Electroencephalography (EEG), raw electrocardiogram (ECG)), Virtual Reality (VR) and haptics.
- "Experience" lists the 3 different kinds of experiences identifiable in the design and UX literature; they are Ergonomic, cognitive, and emotional. Ergonomic experiences are related to usability and effectiveness [15]. Cognitive experiences are related to the aesthetic perception of a product [16]. Emotional experiences involve emotions, affective phenomena, feelings, and pleasure [17].

Table 1. Classification UX of HCI products featured by software ("S") and hardware ("H") components or both ("S/H")

Source	Product	S, H, S/H	Objectives and topic facets	Methods	Instruments	Experience
[18]	Android smartphones models	S/H	UX assessment for design and improvement of products; topic facet: UX evaluation and measurement, design innovations	Data analysis: quantitative and qualitative; participants: final users; environment: controlled	Product representation: end-use products; Support tools: Biofeedback	Ergonomic cognitive
[19]	Information Kiosk	S/H	Effective and satisfying user experience design (UXD), product implementation; topic facet: UX evaluation and measurement, Design for Users, User research methods	Data analysis: qualitative; participants: final users; environment: non specified	Product representation: prototype (virtual prot. of the kiosk); support tools: other devices (laptop)	Ergonomic cognitive
[20]	Conversational Agent and Remote Control Unit	S/H	Measurement and comparison of UX of a conversational agent (CA) and remote-control unit (RVU) for TV control; topic facet: UX evaluation and measurement, Design methods and contexts	Data analysis: qualitative and quantitative; participants: final users; environment: controlled	Product representation: end-use products; support tools: Biofeedback	Emotional cognitive
[21]	Web Documentary	S	Discussion of the impact of serialization and interactivity on audience reception and user engagement; topic facet: Collaboration and team communication, Design methods and contexts	Data analysis: quantitative; participants: final users; environment: natural	Product representation: End-use product; support tools: other devices (users' own mobile and non-mobile devices)	Emotional ergonomic
[22]	Learning Management System platform	S	Usability evaluation of the Blackboard system platform; topic facet: Post-deployment activities and software maintenance	Data analysis: qualitative and quantitative; participants: final users; environment: natural	Product representation: End use product; Support tools: Other devices (users 'own mobile or non-mobile devices)	Ergonomic

(*continued*)

Table 1. (*continued*)

Source	Product	S, H, S/H	Objectives and topic facets	Methods	Instruments	Experience
[23]	Petro-chemical manufacturing plant software system	S	Identification of low-level usability-related software issues; topic facet: Post-deployment activities and software maintenance, Collaboration and team communication	Data analysis: qualitative; participants: final users and experts; environment: controlled	Product representation: prototype (static screen of interface); Support tools: other devices (computer screen)	Ergonomic cognitive
[24]	Traffic Supervision System	S	Usability evaluation of user interfaces of a traffic supervision system; topic facet: Design for Users, Design methods and contexts	Data analysis: quantitative and qualitative; participants: final users and experts; environment: controlled	Product representation: end use product; support tools: other devices (computer screen)	Ergonomic
[25]	Smartphone	S/H	Smartphone User experience analysis and categorization, focus on relation between product smartness and user satisfaction; topic facet: UX evaluation and measurement, User research methods	Data analysis: qualitative; participants: no direct users' involvement; environment: natural	Product representation: prototype (Semantic description); support tools: other devices (computer screen)	Emotional cognitive
[26]	Service provider interface	S	User evaluation of interfaces automatically generated by Egoki system; topic facet: Design-driven software architecture	Data analysis: quantitative and qualitative; participants: final users; environment: controlled	Product representation: prototype (interface generation); support tools: other devices (tablet)	Ergonomic Cognitive
[27]	Input methods for VR	H	Analysis of the performance/effectiveness of different input methods for VR; topic facet: Design innovations, Design methods and contexts	Data analysis: quantitative; participants: final users; environment: controlled	Product representation: end use product; support tools: VR and haptics, other devices smartphone) (computer screen)	Ergonomic

(*continued*)

Table 1. (*continued*)

Source	Product	S, H, S/H	Objectives and topic facets	Methods	Instruments	Experience
[28]	Pop-up warnings	S	Examination of positive/negative emotional response when pop-up warnings appear; topic facet: Design tools and techniques, User research methods	Data analyses: quantitative; participants: final users; environment: natural	Product representation: end use product; support tools: other devices (portable/non portable devices)	Emotional
[29]	Cross-platform services	S	Analysis of user experience of cross-platform services; topic facet: UX evaluation and measurement, Collaboration and team communication	Data analysis: quantitative and qualitative; participants: final users and experts; environment: natural	Product representation: prototype; support tools: other devices (portable/non portable devices)	Cognitive
[30]	Smartphone guide technology	S	Usability evaluation of Smartphone-based guide tour and its effect on visitors 'experience in a cultural space; topic facet: Design for Users, Design tools and techniques, Collaboration and team communication	Data analysis: qualitative; participants: final users and experts; environment: natural	Product representation: end use product; support tools: other devices smartphones and a paper guide)	Ergonomic
[31]	Portable hand grip haptic system	H	Implementation of realistic and immersive interaction with virtual environment through hand grips; topic facet: Design methods and contexts, Design tools and techniques, Post-deployment activities and software maintenance	Data analysis: quantitative; participants: final users and experts; environment: controlled	Product representation: prototype; support tools: biofeedback, VR and haptic devices	Ergonomic Cognitive
[32]	Mobile game	S/H	User experience of augmented reality mobile games (increasing the sense of immersion); topic facet: Design tools and techniques, Design-driven software architecture	Data analysis: quantitative and qualitative; participants: final users and experts; environment: controlled	Product representation: prototype; support tools: VR and haptic devices, other devices smartphone)	Emotional cognitive

4 Analysis and Discussions

The main insights from the analysis follow.

In terms of objective of the study, the outcomes confirmed the results highlighted by Ogunyemi [8], in that UX and usability are the main objectives of HCI studies. Usability is predominantly investigated when the software and hardware components are considered separately. UX is studied when these components are evaluated as a whole system.

In terms of analysis approaches, scholars tend to use both quantitative and qualitative data analysis approaches to study HCI products. However, when both software and hardware are considered, qualitative analysis seems to be more leveraged [18–20, 25, 32]. This highlights that a complex system needs to be considered in a more comprehensive way. Therefore, objective data only is not sufficient to describe and analyze the different facets of UX.

In terms of experimental environment and technologies used as support tools, there is a predominance of artificial settings and controlled environments in HCI experiments (presented in 8 papers). It is worth noting that natural environments are preferred to study the software components of a device only [21, 22, 28–30]. This also reflects the diffuse involvement to involve other devices such as smartphones, tablets, or laptops as support tools in software evaluation (omitted in the classification for the sake of brevity, because of them being standard). When hardware or both components are considered, scholars use a wider variety of support tools, which includes biofeedback and VR technology and haptics in addition to the ones mentioned above [18, 20, 27, 32].

In terms of participants, when UX and the investigation of usability are the focus of HCI studies, final users are involved to perform evaluations. Experts' evaluation was employed in addition to final users only in three cases dealing with the software component only.

In terms of typology of product representation, a balance was found as regards the number of contributions using prototypes and end-use products in their experiments. End-use products are slightly more involved (presented in 8 papers) when the software component is considered.

In terms of typology of experience, the ergonomic experience is the most studied one (presented in 10 papers). Cognitive experience follows immediately, while just a few contributions focused on emotional experience, which is generally studied in combination with other kind of experiences. Ergonomic experience is most investigated when software and hardware components are considered separately. In software it is frequently studied alone [22, 25, 27, 30]. Cognitive experience appears more frequently when software and hardware are considered simultaneously [15, 18–20, 32].

To summarize, complex systems require broader evaluation and analysis approaches. HCI involving both hardware and software components is difficult to be analyzed in a quantitative way only. To have a complete analysis, it is necessary to combine both qualitative (less objective but more wide-ranging) and quantitative (objective but more limited) approaches. This is reflected in the use of a greater variety of technologies and supporting tools for data acquisition and processing. Unlike the ergonomic and cognitive experiences, emotional ones seem to be largely overlooked in HCI research; The importance of emotions in HCI is stressed also by Cristescu [33], who notice a deficiency in emotional approaches and a prominence of traditional cognitive ones. This

this aspect might be seen as a limitation considering transferring HCI approaches to consumer goods and engineering products.

5 Conclusions

This work is intended to get a first understanding of UX and usability in the HCI design field as a trigger to develop UX practices for tangibles. The results achieved are not conducive to conclusive considerations, due to the exploratory nature of this study. A method and criteria for categorizing those kinds of studies represent therefore the necessary first step towards this goal. Based on the proposed approach, the authors examined a sample of convenience of articles proposing case studies where UX is analyzed in combination to the studied software and/or hardware components. To confirm or disconfirm the first insights into HCI, a further analysis of a larger sample of papers is needed. Despite the above limitations, this study was able to capture when software and hardware components are investigated separately or as a whole system, as evident in Sect. 4.

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