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Quantifying the Costs of Conducting Human-Computer Interaction (HCI) research

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Declaration

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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This dissertation is the culmination of my academic career. The last five years that I spent studying at Instituto Superior Técnico had their ups and downs but, in general, are a period I will save with care next to my heart. However, without the help and support of the following people, it would be impossible to get here.

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Abstract

Human–computer interaction (HCI) is an academic subject that studies how technology affects human behavior with HCI becoming one of the most important thematic areas within computer science. The Human Factors in Computing Systems (CHI) conference continues to grow and with a great focus on inclusion and diversity. Although the CHI community has this focal point, the CHI participant sample is dominated by First-world countries. Focused on CHI conferences, this work intends to quantify the Participation and equipment Cost of conducting HCI research, in terms of commercial cost of the apparatus that was used or in terms of participants in the User Testing. This allows to enquire if there is an unequal access to resources, if there is a trade-off between the Participation Cost and the Equipment Cost and if this would impact the publication success or failure in terms of citation count. All papers of CHI were analyzed in order to give an overview about the costs of the HCI regarding the Location/Method of the Study, incentives in user studies and apparatus used in artifacts. It was found that the Participation Cost differs depending on the Location/Method of the Study and the Country, there exists a compromise between acquiring the equipment and the compensation given to the participants and that the Participation and Equipment Cost were not the main influencing factors for the Number of Citations.

Keywords

HCI; HCI Research Cost; Scraper; Bibliometric data; CHI Conference; Visualizations;

Resumo

Interação Pessoa-Máquina (IPM) é uma disciplina académica que estuda como a tecnologia afeta o comportamento humano e sendo uma das áreas temáticas mais importantes dentro da Engenharia Informática. A conferência CHI continua a crescer e estando com maior foco, nos anos mais recentes, na inclusão e sustentabilidade. Embora a comunidade CHI tenha esse ponto de foco, a amostra de participantes da conferência é dominada por países de primeiro mundo. Focado nas conferências CHI, este trabalho pretende quantificar o Custo de Participação e do Equipamento na realização de pesquisas de IPM, em termos de custo comercial do aparelho que foi utilizado ou em termos de participantes no Teste de utilizadores. Isso permite averiguar se há desigualdade no acesso aos recursos, se existe trade-off entre o Custo de Participação e o Custo dos Equipamentos e se esses têm impacto no sucesso da publicação em termos de número de citações. Todos os artigos do CHI foram analisados a fim de dar uma visão geral sobre os custos do IPM quanto ao Local/Método do Estudo, incentivos em estudos de utilizadores e equipamento utilizados em artefatos. Constatou-se que o Custo de Participação difere dependendo do Local/Método do Estudo e do País, que existe um compromisso entre a aquisição do equipamento e a compensação oferecida aos participantes e que o Custo de Participação e do Equipamento não foram os principais fatores de influência para o número de citações.

Palavras Chave

Interface Pessoa-Máquina; Custo de pesquisa em IPM; Scraper; Dados bibliométricos; CHI Conference; Visualizações;

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Acronyms

HCI Human-Computer Interaction

DOI Digital Object Identifier

CHI Human Factors in Computing Systems

IJHCS International Journal of Human-Computer Studies

HAI Human-Agent Interaction

USD US Dollar

CSV Comma-separated values

SIGCHI Special Interest Group on Computer–Human Interaction

GDP Gross Domestic Product

HAI Human-Agent Interaction

GPU Graphics Processing Units

NSF National Science Foundation

PDF Portable Document File

1

Introduction

Contents

Human-Computer Interaction (HCI) is a multidisciplinary field of study focusing on the design of computer technology and, in particular, the interaction between humans (the users) and computers [3]. Human-Computer Interaction research has the emphases on both the ”design, evaluation and implementation” aspect and the ”use and impact in social and organizational settings” aspect of information technology for human use [4]. But creating prototypes and shipping products towards a deeper understanding of what people need.

Due to the nature of this research area, there is a growing sentiment in the HCI research community that this field is reserved to first world countries [5, 6] that can bear the high amount of work in transforming novel research into a product robust enough for widespread use or the high cost of the manufacture of novelty products with the latest devices and fabrication facilities required to conduct this kind of research that is often more easily accepted for publication.

Recruitment of subjects is a significant difficulty in HCI research. Generally speaking, the number of participants and their willingness to participate in the study could be influenced by the study's location and methodology, such as whether it will be conducted on-site or online [7], as well as the compensation the subjects receive [8]. However, not every user study offers incentives. For instance, from the Human Factors in Computing Systems (CHI) conference, our research shows that only 35.41% of the articles with user studies included a reward.

In this Thesis, the only conference that the quantification of the cost of materials, of the devices that were used for prototyping and of the Participation cost spent in user studies, will be the Conference on Human Factors, CHI. The rationale for this decision is due to the CHI being the most important and prestigious conference in the area of human-computer interaction [2]. Another consideration for the choice of this conference was due to the information being publicly available in the DBLP computer science bibliography [9], which is a popular open-data service for the whole computer science community, but also this data is relatively complete and accurate list of the Papers for every year compared with that from other sources. The source for this project can be found at `https://github.com/miguelsequeiradias/Quantifying-the-Cost-of-conducting-HCI-research`.

This dissertation analyzes the papers extracted from the proceedings of the CHI conference from 1983-2022 with the aim of giving insights about the metrics that have an effect on the Equipment and Participation Costs in the HCI community, such as the Location/Method of the Study, the Country and the Citation count and an attempt will be made to find explanations for these differences. We will try to deduct if the HCI research field has a problem in terms of the geographical diversity of publishers of smaller or economically developing countries. This information will be relevant due to the fact that we can analyze which countries have contributed to the conference's success and if it disproves the growing fear of the HCI Research community [5].

While previous research has focused on the Participation of authors or an international representation of CHI participant samples, we will try to take it a step further to quantify the cost of Participation in terms of equipment and terms of recruitment of participants in HCI research and analyze if the unequal access to computing resources plays a critical role on whether a publication is cited by.

1.1 Research Question

H0: What are the Geographical patterns emerging from analysing the Costs of of HCI research;

H1: What are the metrics and what impact do these metrics have on Cost of an HCI article;

H2: Is there a trade-off between the Equipment cost and the Participation Cost while developing HCI research?

H3: Does the Equipment Cost or the Participation Cost have an impact on a paper being cited by?

1.2 Contributions

This work addresses the costs of conducting HCI research and aims to provide us with useful insights about the metrics in which influence the Equipment and Participation costs, whether they are from Geographical or Citation Impact. To achieve this, this work will design and implement a Scraper and a Crawler that will allows us to retrieve the full-text Portable Document File (PDF) of the articles of the CHI conference from 1983-2022.

After retrieving all the data and construct the dataset with all annotated articles, we will analyze the metrics and present visualizations to help understanding what has been done in the world of HCI Research, specifically in the CHI conference, in terms of Equipment Cost and Participation cost and to answer the research questions previously mentioned at Section 1.1.

1.3 Thesis Outline

This Dissertation is organized in 7 chapters. In the next chapter, some context is provided regarding the concepts analysed in the Thesis. In chapter 3 we analyse the related work. In chapter 4, the Methodology implemented and the datasets that were constructed. In chapter 5 we present possible findings of the analysis and investigations. In chapter 6, we discuss the relevancy of the findings analyzed. Finally, in chapter 7 we conclude and give insight on future work to be done.

2

Background

In this section it is presented the Foundational literature around Human-Computer Interaction research. This study starts specifically on its research and focusing on the evolution of HCI research and different methods of studying it and also describing its topics and research activities.

Human-Computer Interaction is acknowledged as an interdisciplinary field where many traditional disciplines contribute to the study of its main issues. It is also, both an academic subject that studies how technology affects human behavior and a design discipline that focuses on making technology more effective. The definition for Human-Computer Interaction according to John Carroll in *Human-Computer Interaction in the new millennium*, HCI

"is about understanding and creating software and other technology that people will want to use, will be able to use, and will find effective when used"

Hewett et al., 1992 [10] also defined HCI as *"a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them"*

Since then, researchers combined the definitions of HCI and focused their investigations on specific closely related focus of HCI research, into two different practices, the **Design** and **Evaluation or Usability** practices [11].

As seen in the definition of HCI above and in the literature, design and evaluation are dividing factors in HCI research [11], and while there is not an agreed-upon definition of either design or evaluation, Daniel Fallman at [12] argued that HCI has emerged *"as a design-oriented field of research, directed at large towards innovation, design, and construction of new kinds of information and interaction technology."* [13, 14] and that *Research-oriented design naturally has "problem solving" within a given paradigm as its main component. It may relate to research, but have the production of new artifacts as its main motivation*.

For Usability the Alan Dix. et al., 2009 defined it as being *one of the core issues in HCI.* and defined it as *the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*.

In this definition, the phrases "Design" and "Usability" are both crucial. While many have argued that design and assessment are intrinsically tied [15–17], they are often separated in practice. The evaluation community (also known as the usability community) is concerned with the evaluation of designed artifacts, whereas the design community is concerned with the creation of artifacts that will be reviewed later. It is obvious that one cannot exist without the other. Both design and evaluation have the same goal of usability, but they go about achieving it in different ways.

As for the research topics in Human-Computer Interaction, they can be of three categories, according to Oulasvirta and Hornbk at [18]: empirical, conceptual, and/or constructive. Empirical research aims to create or improve descriptions of real-world occurrences involving human computing use. Work on a conceptual research problem is aimed at explaining previously unconnected phenomena occurring in interaction. Constructive research aims to produce knowledge on how to build an interactive artefact for a certain purpose in human computing.

To some extent, conceptual development can be detached from hardware, but the evolving course of research and development cannot. The health of the technology industry is tied to ongoing hardware innovation. People are constantly experiencing and embracing digital technologies for the first time thanks to the rapid influx of new hardware, software features, artifacts, and systems. This is essential for artifact producers, and it generates new scientific research questions. CHI has responded by generally focusing on an innovation when it starts to attract a wide audience [19].

It is clear from Figure 2.1 that empirical studies and technology artifacts (Design-Oriented activities research) dominated the research activities of the CHI 2016 community, and that other research contribution types were not only less common, but also less likely to be accepted. Through this bar chart, designing and constructing artifacts can be seen as a core component of HCI research activity [1].

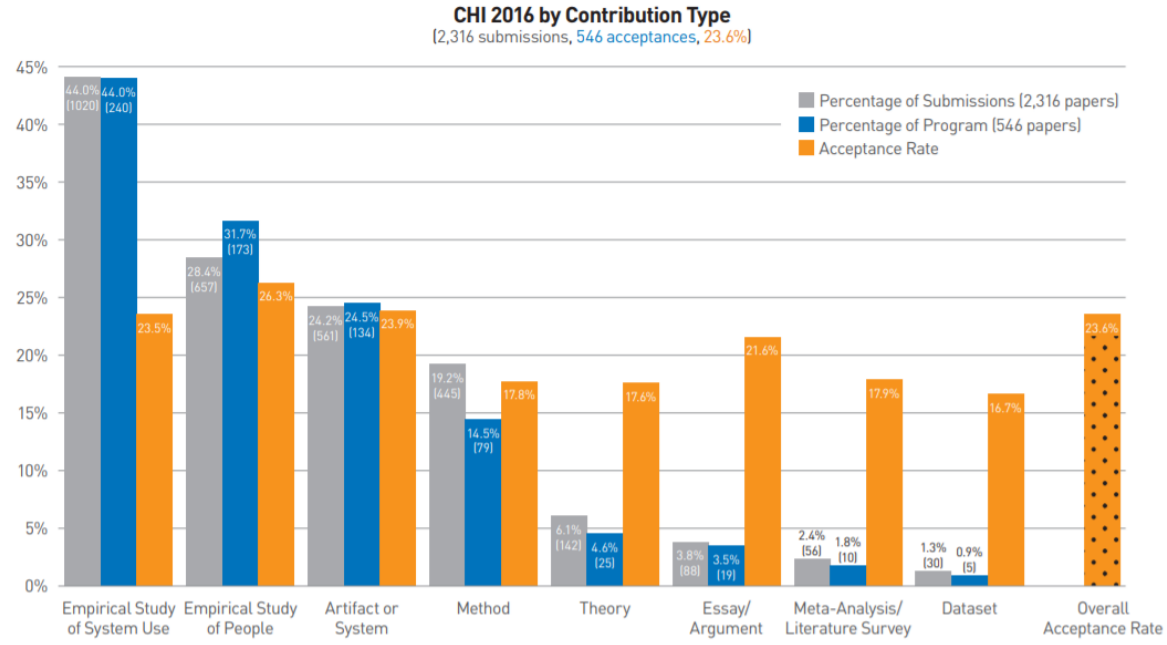

Figure 2.1: CHI 2016 submissions and acceptances by contribution type, sorted by descending number of submissions [1].

3

Related Work

Contents

This section, it is presented the aftermath of searching literature on Human-Computer Interaction, specifically its research. Regarding the HCI research, this work focused on three different insights of research: **Participation, Accessibility and Research Costs**. In order to be easier to analyse each of these insights, these will be divided into the following order:

1. HCI Research Participation, Accessibility
2. HCI Research Costs;
3. Research Papers Analysis

3.1 HCI Research Participation and Accessibility

"The CHI conference continues to evolve in response to community interests, new developments, and strategic initiatives" [20]. Recent CHI conferences, for example, has pioneered a greater focus on diversity and inclusion, work that has a social or political stance [19], sponsored courses to help members communicate with the public, and organized community engagement presentations. The issue of accessibility was originally brought up in the context of physical limitations.

Many community development events have been held at the conferences, allowing members of our community from the Developing World to participate, providing career guidance and networking opportunities for early career HCI researchers and practitioners, and providing mentoring and cohort-building opportunities for underrepresented groups as the Special Interest Group on Computer–Human Interaction (SIGCHI) Executive Committee has made it one of its key missions to nurture HCI growth around the world [21]. But in its nearly 40-year history, the CHI conference, for example, has yet to be held in developing or under developed regions, enhancing global inequities may prevent participation in conferences that are expensive and far.

Jonathan Grudin in *"A Moving Target—The Evolution of Human-Computer Interaction"* [19] discusses that the CHI conferences generally accept 20%-25% of submissions and that this low acceptance rate damages the bridge between academic and practitioner cultures, meaning that few practitioner papers are accepted and fewer practitioners attend the conferences.

Bartneck and Hu [5] stated in 2009 that *"only 7.8% of countries are responsible for 80% of papers in the CHI proceedings"*. Furthermore, they discovered that "almost 80% of all credits go to typically English-speaking countries (the United States, the United Kingdom, Canada, Ireland, Australia, and New Zealand)". The authors also discovered that on average, companies receive 21% of "credits," institutions receive 16%, and academia receives 62% and affirming that according to the results, the growth of the CHI conference is linked to the number of papers and authors having roughly doubled, attributing this, in particular, to Universities.

A substantial number of papers are produced by prestigious universities. This is evidenced by how many of the same institutions have had the most publications at CHI, for example, since 2015 [22]. This is understandable because when there are more resources, monetary or otherwise, there are more papers since there is more time to produce these articles and more practitioners to produce them and can afford the latest devices or better fabrication facilities. Naveena Karusala et al. [23] raises the question that this phenomenon may also feed the bias that papers from elite universities are likely to be more worthy of acceptance (and subsequently have more citations).

With the same focus on grasping the global distribution of authors in CHI proceedings and in the International Journal of Human-Computer Studies, Mannocci et al. [24] detected an unbalanced global distribution of publications in CHI and the International Journal of Human-Computer Studies, as well. The researchers concluded that "there are several countries that show a very high level of interest in what is happening in International Journal of Human-Computer Studies (IJHCS) and HCI but are unable to have a significant publishing presence or citation impact in these outlets."

Tejlavwala, et al. [25] could not uncover any link between the readability of CHI papers and the region of affiliation. Instead, they found that papers with theoretical content had lower readability compared to papers presenting artefacts. Yet, papers with theoretical contributions were more likely to win awards than papers presenting artefacts.

Sebastian Linxen et al. kept on pursuing the context of unbalanced global distribution on [2] and provided an empirical analysis of the degree of the geographic breadth of CHI participant samples. This study revealed that Western participant samples account for at least 73 per cent of CHI study findings from CHI conference of 2016 to the CHI 2020. Furthermore, the authors expanded this prior work by analyzing dimensions of the WEIRD acronym (Western, Educated, Industrialized, Rich, and Democratic) [26], that have not previously been analyzed, namely whether participants come from countries that are more educated, industrialized, rich, or democratic compared to the average world population. The researchers additionally discuss the importance of the participation of scholars from across the world and equitable cross-country partnerships, if we want to address the WEIRD-ness of research at CHI.

As we can observe in Figure 3.1 shows a slight downward trend for Western samples. In line with this, between 2016 and 2020, the share of non-Western participant samples nearly doubled (from 16.31% to 30.24%). Sebastian Linxen et al. explain the significant increase in non-Western participant samples can be attributed to the fact that the percentage of US samples has significantly dropped from 43.56% in 2018 to 27.96% in 2019 (where CHI was held in the UK) and to 24.84% in 2020 (where CHI was to be held in Hawaii before the COVID-19 pandemic forced it to go virtual). This suggests that CHI authors increasingly recruit study participants from other countries than the US and also increasingly study samples from multiple countries.

The final conclusion the authors reached was while quantifying the Geographical breadth of the CHI

participants, and attained that 73% of findings are derived from studies with Western participant samples of which 97% come from countries to which all of the five WEIRD variables can be applied, meaning that the participant sample that publishes in the CHI conference is not representative of the World Population and that 3/4 of the knowledge produced at CHI is based on 11.8% of the world's population.

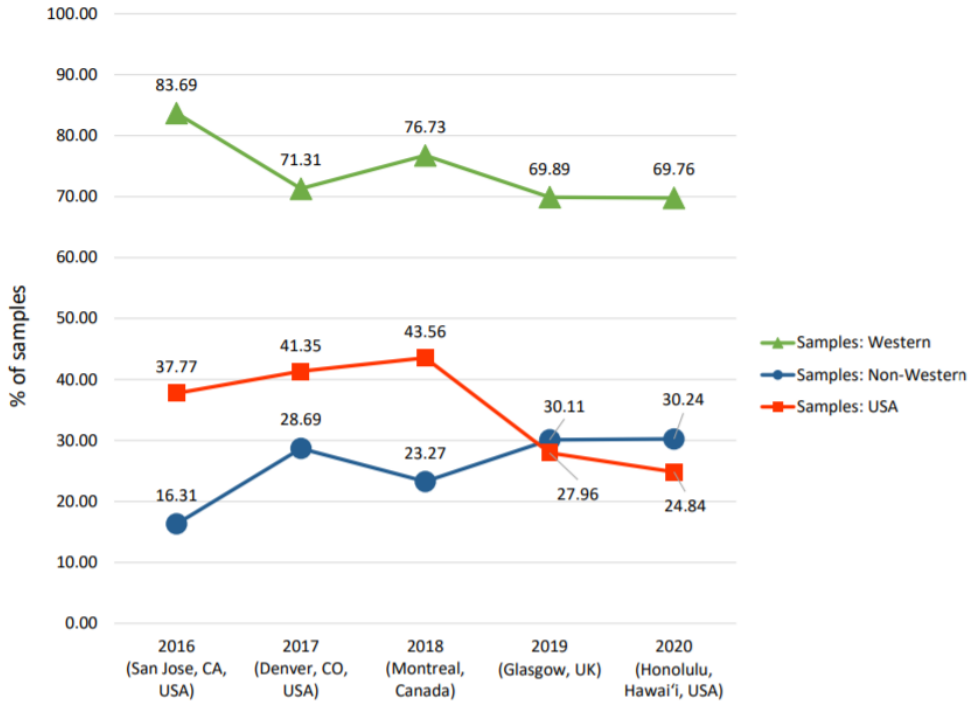

Figure 3.1: Proportion of CHI Western, non-Western and US participant samples, 2016-2020 plus conference locations [2].

3.2 HCI Research Costs

Funding plays a critical role in the quality and performance of scientific studies, such as in the impact factor of journals [27, 28].

According to Jonathan Lazar et al. [29], the funding for HCI is much more sparse and comes through (marginal) participation in programs and projects explicitly directed toward other research communities.

This limited funding for HCI research continues to be a challenge. Neither the German government nor the E.U. Commission has a specific program explicitly devoted to HCI.

Not only is funding scarce, but the type of study supported has shifted in several circumstances. For example, all National Science Foundation (NSF) grant proposals in the United States must demonstrate both intellectual and a larger societal benefit. These tasks involve expanding science while encouraging learning, increasing the participation of marginalized groups, and improving infrastructure for research

and education. Despite the fact that the outcomes of HCI research are frequently socially relevant, HCI researchers will be challenged to better communicate that relevance.

The HCI community has been an active voice in producing an abundance of free, high-quality open-source software. The open access movement, particularly the push for open science driven heavily by the HCI community, continues to increase access to scholarly research, publications, and even textbooks [30]. Despite this fact, only very few CHI papers (less than 5% in 2016–17, see [31]) supply any sort of source code or the software underlying their research contribution is based on but a self-report survey study of CHI authors from 2018–19 offers a slightly more promising outlook, with approximately 20% of authors sharing raw data [32]. While the latter study is subject to self-selection bias, it may indicate that rates of sharing have increased somewhat in recent years.

Chat Wacharamanotham et al. at [32] discuss that sharing research artefacts is a prerequisite for replication (different team, same experimental setup), reproducibility (different team, different experimental setup), or at least a thorough assessment of research validity. The researchers also inspected the low availability of artefacts in the HCI community and found that four factors influence researchers to refrain from sharing artefacts: concern about personally-identifiable data, lack of participant's permission, lack of motivation, resources, or recognition, and doubt in the usefulness of their artefact outside their own study.

Falabi at [33] talked about the Financial challenges in budgetary and the funding constraints of developing research in the Global South and the high cost of Acquisition of equipment. The author discusses how money is a deterrent to how far a practitioner can go and that low budget allocation has decelerated a lot of projects which should have been completed. In terms of acquiring material, the researcher adds that in developing countries, the equipment cost is relatively expensive to secure and that there are not many institutions in the developing world that can afford such a budget in the face of other priorities like staff salaries and scholarships.

Joshua M. Pearce at [34] states that customizing the software has been much easier than custom building equipment, which often can be quite costly and gives examples of how a practitioner can fabricate equipment that can better meet particular specifications at substantially lower overall costs using free and open-source software (FOSS). Although this study focuses on highlighting the benefit of cheaper equipment, the researcher also points out the drawbacks of using open-source 3D digital fabrication versus buying, indicating that commercial equipment may have longer lifetimes and, for instrumentation, may have better statistical validation of calibrations.

According to Vinkler [35], it is possible to believe that grants for research and development do not necessarily depend on market needs, but that they differ between countries because high-income countries can afford to spend more than low-income countries. Sorenson and Fleming [36] surveyed the literature on the relationship between basic science and technological innovation in depth and found that their

analysis of patterns of citations from patents research of patent citation patterns clearly suggests that publishing is a key strategy for increasing the rate of innovation.

Saeed Roshani at [37] pursued the concept of how research funding affects citations of papers in Computer Science, Medicine, and Economics and reached the conclusion that in general, funded documents received more citations than unfunded papers in all three fields. These findings suggest that computer science, medicine, and economics have a high correlation between funding for research and studies being cited at least once. The author compared these three areas of research with a previous study with the same research question, made by Shapira et al. [27] on the field of nanotechnology and attained the conclusion that funding plays a critical role in the quality and performance of scientific studies, such as on the impact factor of journals.

Sarah Hooker at [38] proposes the term hardware lottery to explain how downstream hardware and software choices decisions influence whether a research concept succeeds or fails. Today the hardware landscape is increasingly diversified. This study posits that the hardware lottery has not gone away, and the gap between the winners and losers will grow increasingly larger. The author also argues that lessons from previous hardware lotteries suggest that investment must be sustained and come from both private and public funding programs. In other words, AI firms are often more interested in commercial research meaning that the increased presence of firms may have negative consequences for long-term innovation. In the short to medium term hardware development is likely to remain expensive. The cost of producing hardware is important because it determines the amount of risk and experimentation hardware developers are willing to tolerate.

In the same topic as Hooker, [38], Ahmed et al. [39] explore the access to a large number of expensive equipment that is unrealistic beyond large industrial/academic environments, debating that exist growing phenomenon that the authors called “compute divide” caused by the large computational requirements in Graphics Processing Units (GPU) usage and the researchers’ unequal access to computing resources. The researcher gives the example of research that require millions of dollars in computing power for training AI research and debates that Artificial Intelligence research is being shaped by a few actors, who are mostly affiliated with either large technology firms or elite universities. As a result, this originates a technological push urging AI researchers to seek a corporate association in order to have access to resources beyond what most universities can provide.

3.3 Research Paper Analysis

The term **bibliometrics** was first used, so far as can be ascertained, in the Journal of Documentation, December 1969 [40].

In 1987, Broadus [41] investigated and analyzed the use of the term bibliometrics in the literature

and summarized that *"there does seem to be a clearly delineated body of research involving physical units of publications, bibliographic citations, and surrogates for them. The measurement of these items is called, logically, bibliometrics"*.

The author also gave some insights into the distinctions between bibliometrics and the related term scientometrics when writing: "There is a large area of overlap, then, between bibliometrics and scientometrics, but many of the former deal with matters other than the measurement of science, or scientists, or scientific activity, while, on the other hand, many of the measurements interesting to scientometricians are based on data not derived from publication or other forms of communication."

Bibliometric research methods have been popular in the fields of Human-Computer Interaction [5, 42–44] and can be beneficial in understanding research effort, behaviour, structures, growth, and impact [45]. Several bibliometric studies of conferences conclude with informed advice to the conference organizers [46, 47].

By providing a top-down overview of the state of a field, these bibliometric reviews can provide jumping-off points for new ideas, especially for researchers first entering a field. In our case, we focus on citation analysis as one way of assessing the interdisciplinary of the accessible computing community, where as far as we know, such analyses have not been conducted before. As argued by Kaye [42], it is healthy to occasionally take an introspective look at a research field.

Bibliometric data facilitate easy comparison of researchers and are increasingly used for recruiting academics, promotion, tenure, and allocating funding [45] but such data must be used with caution as publication and citation counts can only give support to hypotheses of causalities [48].

Bartneck and Hu [5] examined the nature of the CHI conference proceedings over a period of 25 years (1982-2008). This study analyzed the trending pattern of publications at the conference series, authors' affiliated countries and the types of authors' organizations (e.g. universities, institutes and companies) and focused on both quantity and quality, including numbers of citations and best paper awards. This bibliometric method allows Bartneck and Hu to expose the lack of geographical diversity of the CHI Proceedings revealing that only 8% of the world countries are responsible for 80% of the papers as it was previously mentioned in section 3.1.

Daisuke Sakamoto at [49] revisited Bartneck and Hu's study with the purpose of viewing the evolution of Asian researchers' activity, noticed that Bartneck and Hu's results were no longer representative due to rapid growth in Asian Participation since 2009. While Bartneck's research was more broadly focused on both quantity and quality, including the number of citations and best paper awards. Daisuke Sakamoto's study was done with a limited data source. Due to this limitation, the author's only focus was on the quantitative analysis, including geography, organization, and author statistics. Daisuke Sakamoto employed the same method that Bartneck and Hu had used, the idea of credits, and reached the conclusion that Asia is a rapidly growing region in HCI research, and the results indicate that there is room

for more growth.

In the same manner as Bartneck at [5], Omar Mubin et al. at [47] analyzed the Human-Agent Interaction (HAI) Conference which is the premier discussion venue on the topic of Human-Agent Interaction with a scientometric analysis of full papers from the HAI conference since its inception to 2017.

In this research, the authors focused on measures to gauge the impact and growth of conferences and used a variety of measures such as bibliometric metrics, collaboration networks, citation likelihood and key topics. The author with the results of this bibliometric analysis, uncovered that the HAI conference in terms of the number of presented papers was consistent throughout the years, the ratio of returning authors over the first few editions of the HAI conference was particularly low and which user-studies were the most common research approach.

Frode Eika Sandnes at [45], inspired by Bartneck's work at [5], explored a bibliometric study of HCI research activity in the Nordic-Baltic countries.

The Bibliometric methods were based on publication counts aggregated at a national level as a measure of active research participation and were used to collect empiric evidence about HCI research activity, longevity, choice of publication type, collaboration, and citation impact.

The author analyzed the research activity according to absolute publication counts, as well as these publication counts normalized according to the respective Gross Domestic Product (GDP) and the country population sizes. This allowed the researcher to rank HCI research activity in the Nordic-Baltic countries. Sweden, Denmark, and Finland consistently published most papers and these three countries are also the most populated countries with the largest economies.

The findings of Frode Eika Sandnes on how frequently was the Nordic-Baltic research cited was that the research quality does not seem to vary much across the Nordic-Baltic countries as there are relatively small differences in mean citation counts and concluded citation impact results were consistent with the perceived status of the conference tier, as conference papers published at the top-tier were more frequently cited than work published at the regional-tier and lowest for papers published at the entry-tier. Journal articles accumulated the most citations.

Lucy Lu Wang et al. at [50] examined the relationship between accessibility research and these connected fields using bibliometric and citation analysis methods with the goals of finding citation patterns of accessibility research published at CHI and ASSETS, the latest mentioned being a premier forum for presenting research on the design, evaluation, use, and education related to computing for people with disabilities and older adults. The other goal of the researchers was to study what are the trends over time and how are they evolving and to these trends relate with other HCI communities. This analysis revealed that the analysis of citation diversity for accessibility papers revealed that though these papers are predominantly influenced by other works in accessibility and HCI, they also draw influence from disability studies, psychology, and other fields and whether an accessibility paper is published in CHI or

ASSETS produces little difference in its number of citation outcome, though the venues as a whole are rather different.

3.4 Discussion

In this section, we will be discussing the pros and cons of the studies from the state of the art that is suitable for our Dissertation.

With our Thesis in mind, we started by analysing the global distribution of the Equipment Cost and Participation Cost of each publication of the CHI Proceedings.

Right away we can find that the SIGCHI Executive Committee has made it one of its key missions to nurture HCI growth around the world and has pioneered a great focus on diversity and participation around the globe. Although this focus on Diversity, the studies made by Bartneck and Hu [5], Mannocci et al. [24] and Sebastian Linxen et al. [2] confirm that despite this effort mentioned to increase participation, this conferences publications were dominated by Western and English-speaking countries and are considered First-World countries meaning that the participant sample that publishes in the CHI conference is not representative of the World Population and that 3/4 of the knowledge produced at CHI is based on 11.8% of the world's population. In spite of the fact that there is a lower participation of countries of the Global South, this percentage seems to be increasing in the most recent CHI proceedings, showing that the participation sample is becoming more geographically diverse. The research papers previously mentioned are a great example of studies that provide knowledge of the representative participant samples of the CHI conferences and will be used in the Discussion chapter 6 to gather additional results and conclusions of trends and perspectives.

Secondly, we talked about HCI Research costs how the limited funding for HCI research can be a challenge, how financial challenges and the High cost of Acquisition in developed countries can be a deterrent for a practitioner, and lastly if Hardware and/or software choices decisions can impact whether artefact research can succeed or fail. This related work will be useful since we will try to quantify and estimate the cost of a publication in terms of Equipment and Participation Costs and answer the Hypothesis Question **H2** and **H3**. The research papers mentioned in the Section 3.2 are a great example of studies that provide knowledge of the difficulties and also of the Geographical Disparity there is in terms of Equipment and other deterrents for the Participation in HCI research and will be used in the Discussion chapter 6 to gather additional results and conclusions of the Equipment and Participation Costs.

For the Research Paper analysis, in our proposal, we will make use of the bibliometric studies presented to help us support hypotheses and comparisons between publications. The Bibliometric research is relevant to our work since we are analyzing if conducting HCI Research has a barrier of cost, i.e. if the higher cost devices and higher incentives offered to the participants results in a higher frequency of research citation count. This will also be a limitation of my study since a citation count is an indication of scholarly interest; it is not the ultimate measure of societal impact. Citation context is also important. For instance, a negative citation, i.e., a citations under criticism, will still count as one plus citation [5, 45].

4

Methodology and Implementation

Contents

This Thesis is based on Quantifying the Cost of Conducting HCI Research and for this, we first need to collect the data based on the contributions of the CHI conference which the analysis and the visualization will be made upon to help understand what has been done in the world of HCI Research. In this chapter, we explain in some detail how this collection and construction of the dataset was made and then introduce the metrics that are considered in the further analysis in chapter 5 "Findings". Additionally, for the sake of rigour and reproducibility, we also describe the steps on which the data will be analysed and also the dataset used to analyze and make the visualizations to answer the Research Questions.

4.1 Data Collection

The collection of data is based on contributions of the CHI conference to quantify the costs of conducting HCI research. A systematic literature collection of all papers published at the CHI conferences was conducted. Some data, e.g., Apparatus and Participants, was extracted manually from each paper and saved in a spreadsheet.

The spreadsheet contains columns for the Participants' details (Number of Participants, Gender, Location of the Study) the Bibliometrics details (Authors, Year of Publication, Citation count, Affiliation and Country), the Equipment/Apparatus details (Name of equipment) and the quantifiable Cost of the paper (Equipment Cost, Compensation, Compensation Amount, Participant Total Cost and Total Cost).

Firstly we will discuss the implementation of the Scraper and the Crawler that allowed us to grab the data (Digital Object Identifier (DOI), Title of Article and Authors) and download the articles from the CHI Conferences in PDF format. Notice that there was no CHI conference in the year 1984, and hence no data is available for that year.

After obtaining the article's files from the Crawler, the focus of our work was directed to search all of the articles downloaded for several keywords to construct the base of the dataset in terms of Participants and in terms of Equipment. Succeeding the keyword search and quantifying the participation and the equipment used in the Articles, the next step is to evaluate the geographic diversity of CHI and the Bibliometric Data to finally analyse the dataset as a whole.

4.1.1 Scraper and Crawler

Through this subsection, we will introduce and discuss all the details of the implemented Scraper and Crawler, listing the tools, the technologies used and the choice for their selection.

Firstly, we need to obtain the DOI for all the articles of the proceedings from the beginning until 2022. For the development of both the Scraper and the Crawler, it was used exclusively the Python programming language [51] and the use of Beautiful Soup [52] for their speed, documentation and learning simplicity [53, 54].

Before developing the Scraper, we decided the best place to scrape each of the proceedings of the CHI was the DBLP computer science bibliography due to being a popular open-data service for the whole computer science community and having the complete list of the Papers for every year. After concluding the development and running of the Scraper, it was obtained from all papers (N = 9688), their DOI, Title, Authors and the Year as Comma-separated values (CSV)-files. Searches were conducted on June 2022.

After acquiring the DOI and the Title of the Papers, the next step was to download the full-text PDFs of the papers. This step was complicated due to Google Scholars bot detection and CAPTCHA and also the End-User Policy of the ACM Digital Library. To bypass these complications, the Crawler was developed using the Scholarly API [55], which is a Python package third-party solution that supports publication search results. The Scholarly API along with the Request Library from Python, an interval timer of 1 minute and a dynamic TOR proxy was a solution we found to secure the download of the full-text PDFs of the Papers (N=9688) in a non-invasive way. The crawler was run 2 times taking 2 weeks for each run. The Crawler was launched from June 2022 to July 2022.

Finally, our corpus of data was collected online across all the CHI proceedings and almost all the full-text PDFs of the papers were downloaded. Due to file corruption in the Computer, the full size of the dataset was 8892. The code for performing the Scraping and the PDF extraction can be found at https://github.com/miguelsequeiradias/Quantifying-the-Cost-of-conducting-HCI-research

4.1.2 Geographic Data

In an effort to evaluate the geographic diversity of CHI, we used the Scholarly API [55] while we were downloading the full-text PDFs to also extract the Author's ID for that publication. With this Author ID, it was possible to also extract the Affiliation and Country of origin from the Author profile using the search author query available from the Scholarly API.

But this was not possible for all the authors, so with the available and open access Supplemental Material from Sebastian Linxen et al. [2] it was possible to cross-reference the missing authors with the Author names that were scraped from the DBLP to obtain their Affiliation and Country. However, the authors themselves used inconsistent names. Alan Dix, for example, is also listed as "Alan J. Dix". We, therefore, used the *theFuzz* [56], a Python Library, which implements a Fuzzy string matching that uses the Levenshtein Distance, to match two string sequences approximately in a ratio of [0,1] to group the aliases of authors together.

4.1.3 Keyword Search

Regarding the Keyword Search for the full-text PDFs of the papers, we decided to quantify the cost of the Papers from the CHI proceeding in two topics:

- **Participation:** Recruitment of participants for user studies and the challenges they face in doing so and if they received Compensation;
- **Apparatus/Equipment:** Hardware or Software equipment that has a known commercial value shared in the Papers.

In order to extract the keywords from the PDF, the Python package PyMuPDF [57] is used. PyMuPDF has various functions that enable us to interact with the PDF on a deeper level, including extracting text spans and identifying paragraphs, tables and lists but has the limitation of failing to read scanned PDFs (early years of the CHI Conference).

The breakdown of the keywords used for the search was taken into account for each topic is shown at 4.1 and they were chosen due to the definition of the Keyword itself, but also for appearing more frequently as Section names in random Papers that were previously open to pursuing keywords that could be used to Keyword Search for Equipment.

Table 4.1: Keywords considered in the Analysis of the Topic

Topic	Keywords
Apparatus	Apparatus, Implementation, Setup, Hardware
Participation	Participants Subjects, Paid, Given, Compensated, Reward, Gift

4.1.3.A Apparatus/Equipment

In terms of equipment, Chat Wacharamanotham at [32] surveyed authors of CHI 2018–2019 papers, and only around 28–50% of the authors shared the software and hardware that was used in the artefact. the top three reasons against sharing are consistent in hardware and software future research value, commercial value, and that they do not make sense outside the original context. With this information, we can say that we can not quantify the equipment for every publication.

Only the articles that had the keyword at 4.1 in their full-text PDF-file were manually open (N = 1899) and where we scraped the equipment and cross-reference manually to a known price that was included in our CSV-files (Equipment name). This equipment name was then used as a search term on Google, together with Google's search results by Date tool to the year of the Paper. This allowed us to find the commercial value of the equipment in that year in US Dollar (USD) that was also included in our CSV (N = 1040) (Total Cost). This process took about a week to manually search all download papers.

4.1.3.B Participants

The recruitment of participants is a significant barrier to this research methodology. Low response rates or a lack of diverse participants are frequent problems for researchers, as noted by Barkhuss [58]. In addition to the previously listed elements, incentives are crucial in attracting new subjects [8]. For this reason, we determined that determining the number of participants utilized in user testing or in other types of involvement, as well as the compensation they were paid, is a useful approach to also estimate the cost of conducting.

We felt that the insight gained from a potential analysis of all CHI papers would not outweigh the massive task of manually searching n=(7965) papers. So, only selected years of research were studied in depth. We choose five years' worth of papers, most with an at the most four-year gap. The years chosen were 1983, 1987, 1991, 1996, 1999, 2001, 2004, 2007, 2011, and 2016 til 2022 (N= 4884). This process took us about 2-3 weeks to complete due to the number of Papers that had to be manually searched.

The first column of the CSV file indicates the total number of participants, while the next two columns list the participants' genders. The number of female participants is shown in the first column, and then the number of male participants is listed in the second column. The age of the participants was not recorded due to we did not see the relevance of keeping this information. Regarding the Location of the study, online studies are conducted via the Internet or other type that isn't in a controlled environment. For all other studies, it is listed as an on-site. We decided to insert Surveys as Location although they are a method of study since they are the most frequent and we did not want to lose this type of data. The spreadsheet's rows each correspond to a different study. Studies without human subjects are not eliminated from the data collection, but they are also not further examined in terms of the aforementioned factors. The amount of compensation is given in USD as the average amount in USD that each Participant received. Other currencies were converted to USD between September and October 2022 using a Currency Converter, in this case, Google.

For papers that contained several User Studies, the Number of Participants was added if the Location of the Study was the same and their average compensation would be inserted in the Amount of Compensation variable. If the Location of the Study was different, e.g. On-site and Online, we would only insert the Number of Participants of the first experiment but the Total Participation Cost would be for all User studies.

4.1.4 Bibliometric Data

In order to determine impact on the computer science research community of the CHI conference, we recorded the number of citations of each paper as indicated on Semantic Scholar. CHI papers tend

to appear on other repositories such as Scopus and Google Scholar but due to more complicating scraping policies, we considered Semantic Scholar as our preferred outlet for noting citations. This was done using the Semantic Scholar API in Python and and was used to obtain the Citation Count that was included in our CSV-files. The citation data was recorded in one day during the mid of October 2022.

Bibliometric methods were used to collect empiric evidence about HCI research activity, longevity, and citation impact.

4.2 Data Analysis

The data set was analyzed using Tableau [59] which is a data visualization tool that sits between the end-user and the CSV-file and allows the user to create visualizations by dragging and dropping fields from their datasets onto a visual canvas. We used Tableau instead of creating the visualisations using Matplotlib or other tool due to the quickness of creating visualizations, simplicity of creating multilayers geospatial visualizations and previous experience in working with Tableau. It should be noted that the scales of the box plots and other visualizations were intentionally reduced to emphasize on the more typical values rather than outliers and to more clearly indicate discrepancies.

Categorical factors are described with frequency distributions to gain a quick overview of the data. For each distribution, only those studies are taken into consideration that gives information on the relevant factor. Therefore, for each inquiry, the total number of included papers, N, is provided. The Categorical factors that we will analyze are the Location/Method and the Country of the Studies. Regarding the frequency distribution of the Location/Method, all social media channels that originally occurred in the data set (Facebook, Instagram, Reddit, Twitter) or Interviews that occurred in (Skype, Zoom) have been combined as *online*. In the same manner, all surveys different from Amazon MTurk [60], Qualtrics [61], Prolific [62] and SurveyMonkey [63] were combined to *survey*. Regarding the Country, we will be only exhibiting in a visualization (except for the Map Chart), a maximum of 25 countries to be able to focus on the biggest contributors and the countries with higher publication count.

For **quantitative** factors, it is first tested whether they follow a Normal Distribution. They are described by giving the mean and range of values as well as using box plots to identify the median and outliers of the data points. Once more, only studies that provide details regarding the factor under analysis are taken into account. The factors that we will be investigating are the Number of Participants, Equipment Cost, Amount of Compensation, Participation Total Cost and Total Cost of the publication (Equipment Cost + Participation Cost).

For the investigation of metric factors, scatter plots were generated and Pearson's correlation coefficients were calculated. For this, identified outliers were excluded.

The correlation coefficient *r* is reported in chapter 5 "Findings". We interpreted the ratios, as Jenny Reinhard did in [64], as follows:

- **Weak correlation:** r = .10 to .29 or r = -.10 to -.29
- **Moderate correlation:** r = .30 to .49 or r = -.30 to -.49
- **Strong correlation:** r = .50 to 1.0 or r = -.50 to -1.0

After focusing on the description of a single variable, it was interpret what has been done in the world of HCI Research in terms of Participation and Equipment Cost that will allow us to answer the Research Questions we proposed. We investigated whether there are differences in the Number of Participants according to the Location and the Country of the study, using Box plots for a quick graphical examination of the Descriptive statistics (Median, Quartiles and Outliers) but we also analyzed the statistical relationship, using a Pearson's Correlation between the Number of Participants and the Compensation Amount, Equipment Cost and Total Cost (Participation Cost + Equipment).

The second variable examined was the Location/Method of the Study, and it was analyzed whether the Location/Method of the Study had an impact on the frequency and amount of compensation, with the Participation Cost. All of these analyses were graphically demonstrated by using a Box Plot except the Frequency of compensation which was analyzed using a Bar Chart with the percentages.

The third variable explored was the Equipment Cost of the Study. We investigated if the Equipment Cost was impacted by the frequency and amount of compensation and also examined the evolution of the Equipment Cost per year of the CHI Conference.

The fourth variable investigated was the Participation Cost of the Study. We analyzed if the Participation Cost was impacted by the Equipment Cost. This analysis was graphically demonstrated by using a Scatter Plot and by computing Pearson's Correlation. We also examined the evolution of the Participation Cost per year of the CHI Conference.

The fifth variable analyzed was the Geographical Distribution of the Study. We investigated the frequency of Location/Method of the Study and the frequency of compensation for the Top 20 countries by the number of Papers published. After this step, it was demonstrated graphically by using Map Charts, the Geographical Diversity of the CHI conference regarding the Number of Participants, Participation Total Cost, Equipment Cost and Total Cost of Publication.

In the sixth and final step of the analysis, it was analysed whether the Participation Total Cost, Equipment Cost and Total Cost of the publications would be one of the main factors that could explain the differences in the number of citations. For this, the variables described previously were examined using Pearson's Correlation with regard to the number of citations of the publication.

4.3 Description of the Dataset

The dataset consists of 8892 papers, this corresponds to the 26711 rows with different Authors for the same paper in the CSV-file. The number of participants ranges from 1 to 81,131 with a median sample size of 20 (N= 3,362). Sample sizes that include more than 89 participants are counted as outliers (see Figure 4.1). The dataset is available in https://github.com/miguelsequeiradias/Quantifying-the-Cost-of-conducting-HCI-research/blob/main/dataset.csv.

The sum of the Participation Cost with the Equipment Cost gives places to the Total Cost metric. This total cost of a publication ranges from 1 to 176,000 USD with a median sample size of 500 (N= 6,887). Sample sizes that include a cost higher than 2,898 USD are counted as outliers (see Figure 4.2).

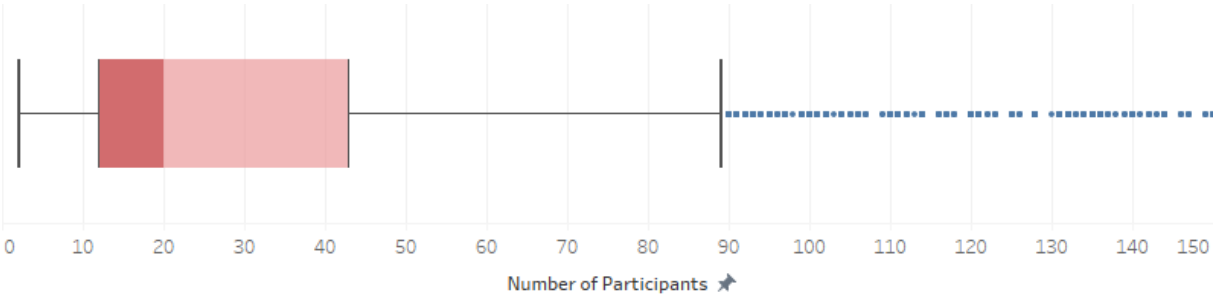

Figure 4.1: Number of Participants.

The amount of compensation ranges from 0 USD (Volunteers) to 632 USD with a median amount of compensation of 13 USD (N= 1594). Compensation amounts higher than 50 USD are counted as outliers (see Figure 4.3). In regard of the Participation Total Cost of Users (this also includes the existence of a bonus to some Participants or of a Lottery compensation, or a coupon), it ranges from 0 USD (Volunteers) to 50,700 USD with a median amount of total participation cost of 320 USD (N = 5,464). Total Participation amounts higher than 1,830 USD are counted as outliers (see Figure 4.4).

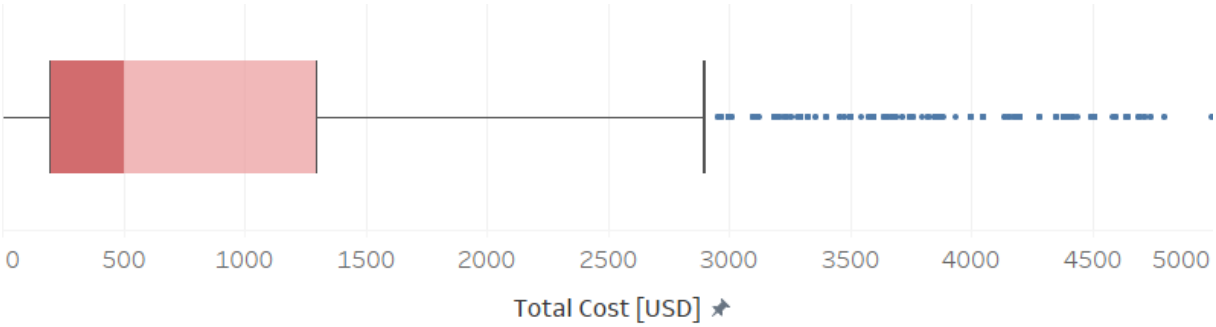

Figure 4.2: Number of studies that have a total cost associated.

The cost of Equipment/Apparatus ranges from 5 USD to 176,000 USD with a median sample size of 850 USD (N= 2,187). Sample sizes that include a cost higher than 4,400 USD are counted as outliers (see Figure 4.5).

Regarding the studies in which the Location/Method that includes human subjects is indicated (N= 12,223), 58.94 % of all studies took place in the on-site, 27.06 % online and 7.17 % took in Amazon Mechanical Turk. The absolute number of studies that include a specific method is visualized in figure 4.6.

Regarding the Country with most published Papers in the CHI conference, the absolute number of Studies made for each country is visualized in 4.7, revealing that in Rank 1 of most publications made by a country in the CHI conference is the United States of America, followed by United Kingdom and Canada.

Outliers for the number of Participants, Equipment Cost/Total Cost and for the amount of compensation can be explained by the large number of study features with high variety of characteristic values. For each will be given an extreme example or a explanation:

1. A study with 81,131 which was an online experience to analyzed the impact on sharing behavior.
2. Silicon Graphics Inc. ONYX2 which is a a 250,000 USD graphics supercomputer from 1993 was used for an Article in 2001;
3. And for the amount of compensation, a limitation of our Thesis is that the Duration of the study wasn't analyzed and this can impact the amount of compensation received, i.e., a participant is more likely to receive an higher amount of compensation if the study lasted more time [65].

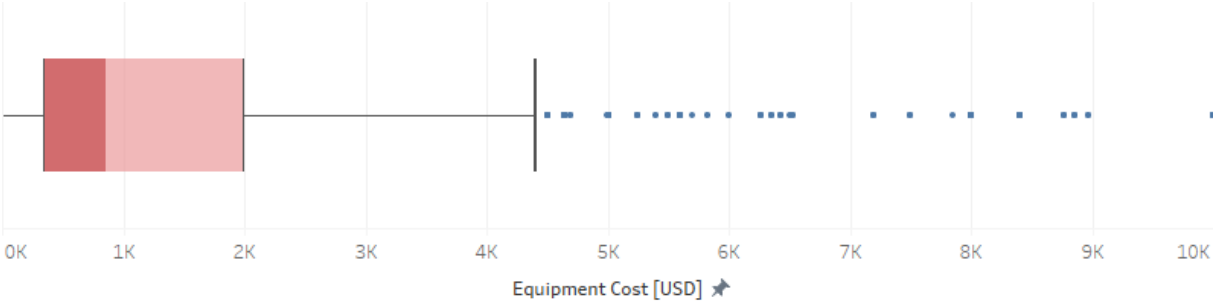

Figure 4.3: The Amount of Compensation.

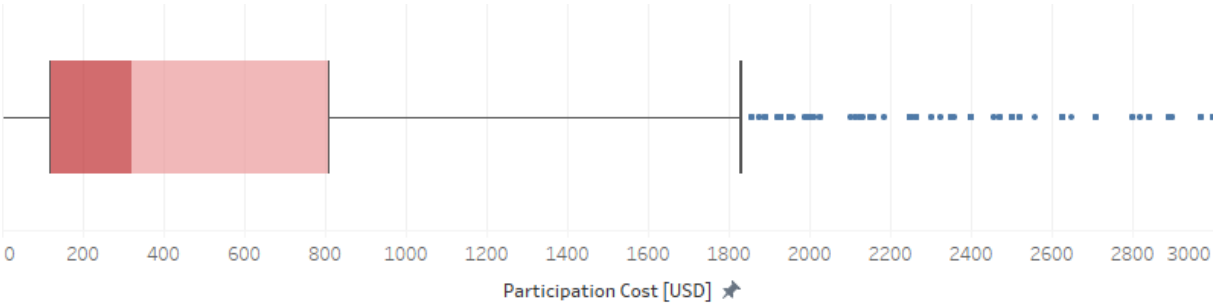

Figure 4.4: The Participation Cost

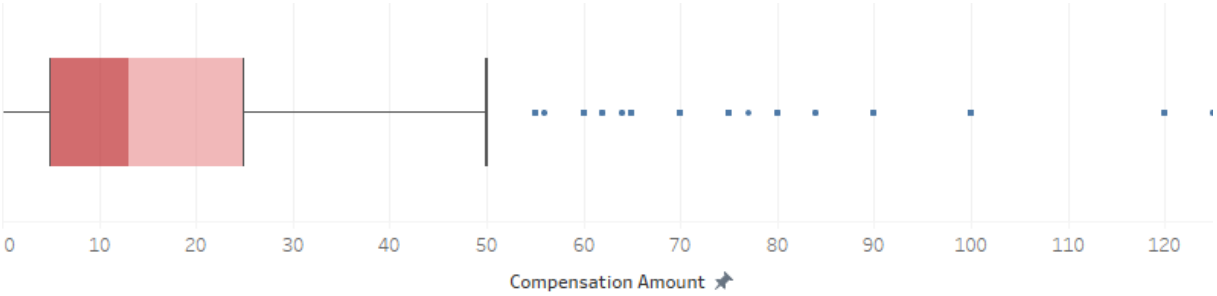

Figure 4.5: Number of studies that have a Equipment cost associated.

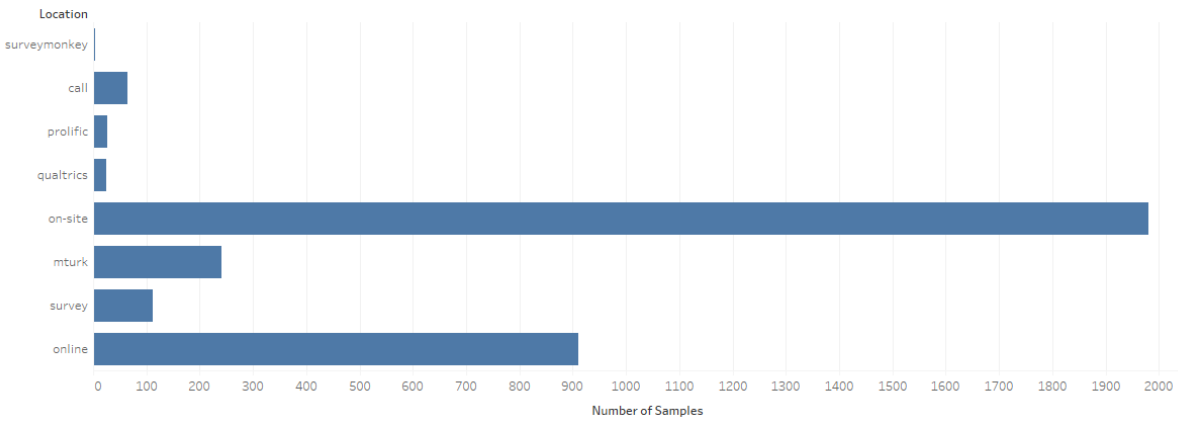

Figure 4.6: Number of Studies according to the Location/Method of the Study.

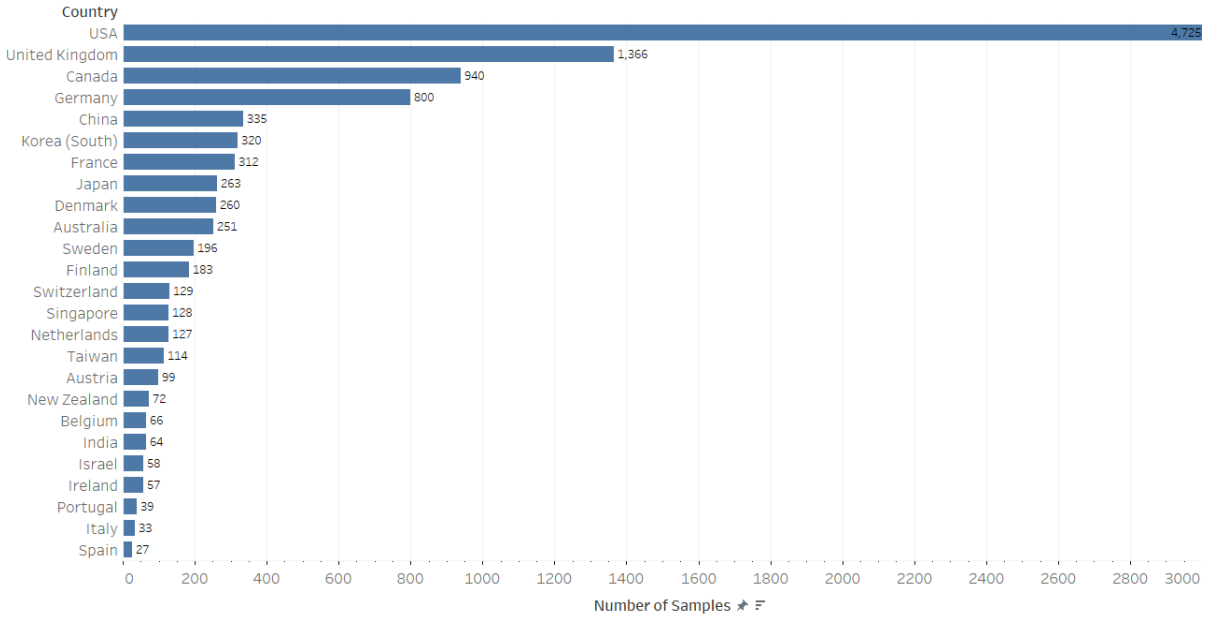

Figure 4.7: Top 25 Countries with the most Papers published in CHI.

5

Findings

Contents

In the following chapter, the findings of the analysis are presented. For this search, we will be examining the the differences in the articles published in CHI conference according to data collected and previously described and we will describe the analysis and visualizations created that will help interpret what has been done in the world of HCI Research in terms of Participation and Equipment Cost and that will allow us to answer the Research Questions we proposed. In order to explain these differences, the following factors that are investigated:

- **Number of Participants**
- **Location of the Study**
- **Equipment Cost**
- **Participation Cost**
- **Geographical Distribution**
- **Number of Citations**

5.1 Number of Participants

The number of participants is the first component being looked at to determine causes for the variances in Total Cost according to the various criteria in the articles presented in the CHI conference. It is examined to see whether there are variations in sample sizes depending on the Location/Method or the Country, as well as any relationships between the number of participants and the amount of compensation (N=4857), the cost of the equipment (N=1645), and the overall cost (N=6435).

Figure 5.1 and Figure 5.2 show that the sample size differs depending on the Location of the Study, the median number of participants is 225 and 300 for MTurk and Qualtrics respectively, and the Country where the median number of Participants for the USA is 21, where in the United Kingdom is 16. Relative to the Location of the Study, it shows that Studies on-site that have more than 48 participants are counted as outliers and Studies that happened online that have more than 108 participants are counted as Outliers.

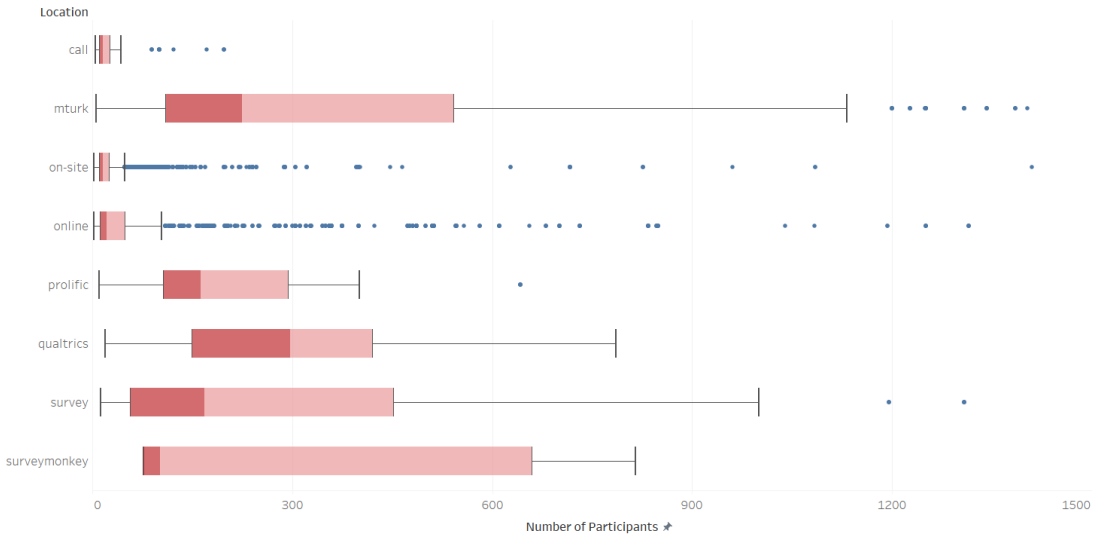

Figure 5.1: Number of Participants according to the Location of the Study.

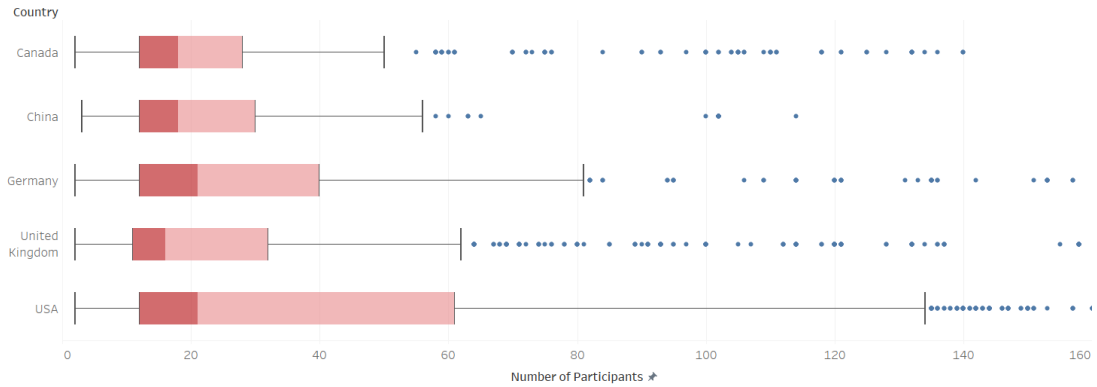

Figure 5.2: Study Participants according to the Top 5 most published Countries.

The scatter plot of the number of participants and the equipment cost is shown in Figure 5.3. A small positive link between the number of participants and the equipment cost was found using Pearson's correlation coefficient (r = +.002). It should be emphasized that the scales of the scatter plot were manually reduced to concentrate on the more typical values rather than the outliers, and only the visible markings on the plots were utilized to compute Pearson's correlation coefficient.

Figure 5.4 shows the Scatter plot of the Number of Participants and the Amount of Compensation. Using Pearson's correlation coefficient reveals a weak negative correlation between the number of participants and the Amount of Compensation (r = -.07).

Figure 5.5 shows the Scatter plot of the Number of Participants and the Total Cost. Using Pearson's correlation coefficient reveals a weak positive correlation between the number of participants and the Total Cost (r = +.003).

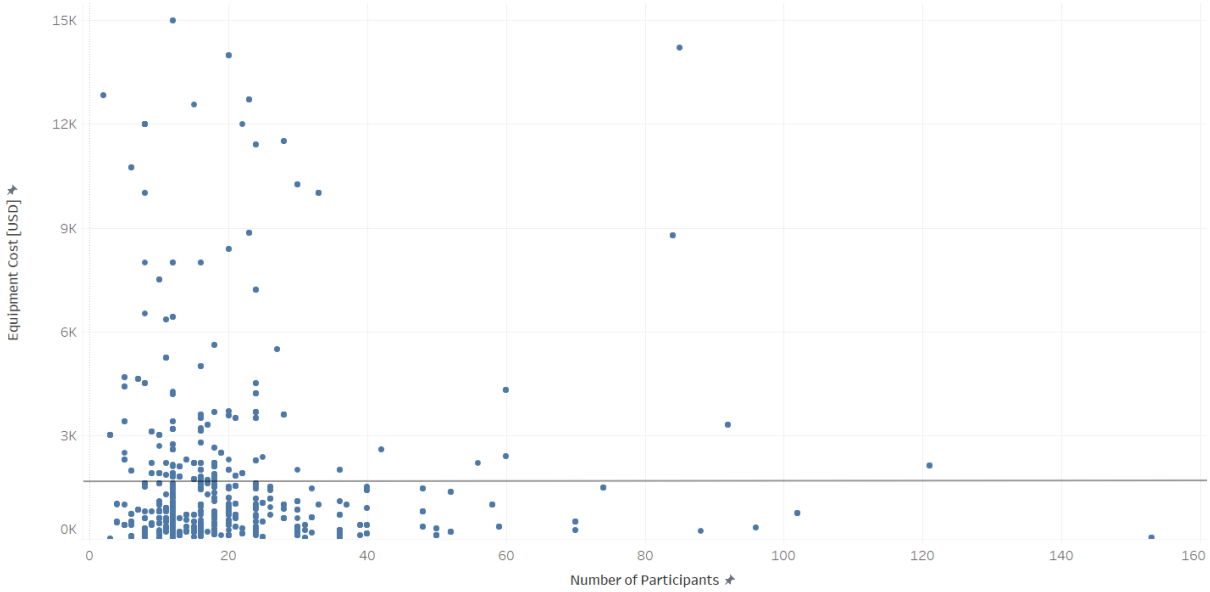

Figure 5.3: Number of Participants and Equipment Cost.

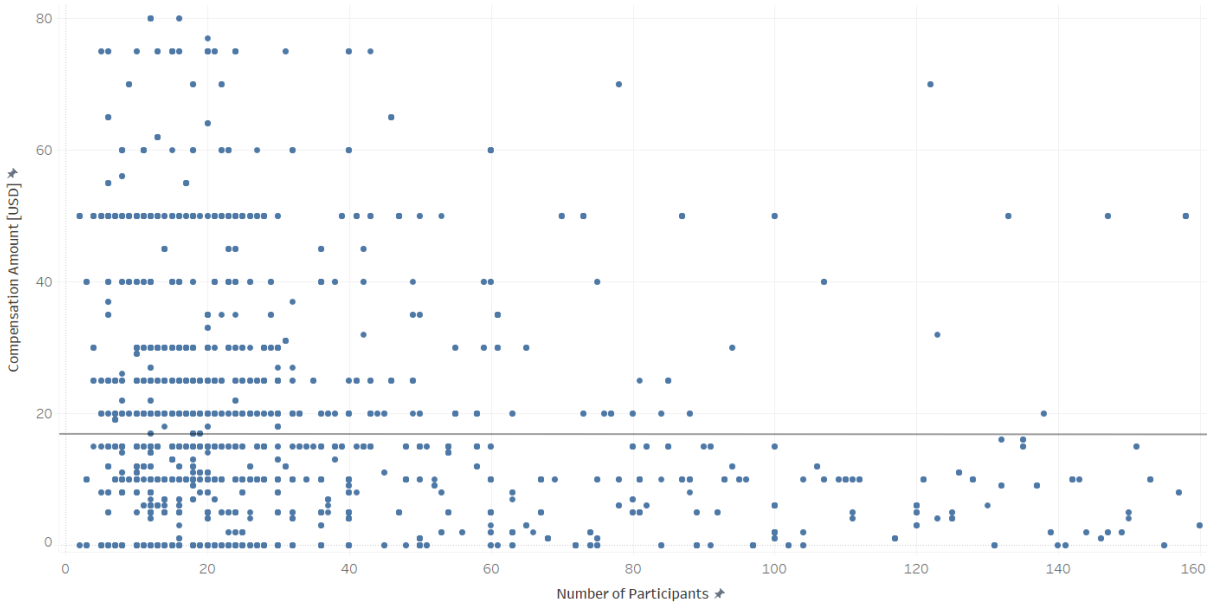

Figure 5.4: Number of Participants and Compensation amount.

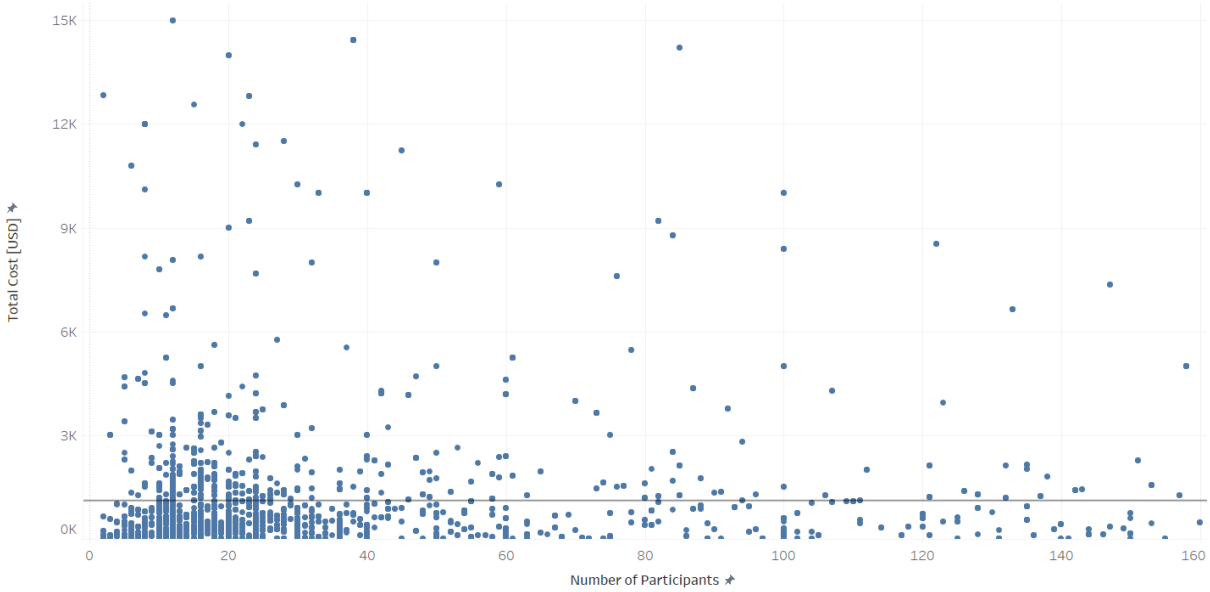

Figure 5.5: Number of Participants and Total Cost.

5.2 Location of the Study

As the second factor, the Location of the Study is explored. Again, it is analyzed whether there are differences in the sample size between the Number of publications or the number of Participants and the differences in the frequency of compensation. It is also investigated whether the location itself is a reason for these differences in the Amount of Compensation.

It can be seen from Figure 5.6 that Participants were most likely to receive compensation when the Location of the Study was through *Prolific* and *Qualtrics* (100%), followed by recruitment in *Amazon MTurk* (91.70%), *SurveyMonkey* (50%), *Online* (46.69%), *Survey* (42.34%). Participants who were involved in the Studies *On-site* and by *Calls* were least likely to receive compensation. They were compensated at 42.15% and 20.31% respectively.

The median compensation is highest for those taking part in Users studies online (med[”Online”] = 20 USD) and lowest for those taking part in calls (med[”Call”] = 0 USD), as shown in Figure 5.7. Prolific, Qualtrics, and Amazon MTurk rewarded participants with amounts ranging from 3 to 6 USD on average. On-site studies were paid out in a median amount of 15 USD. An example of a Study located *Online* with a Amount of Compensation of 20 USD, is the article of Jonas Schjerlund et. al., from Denmark, published at the CHI 2022, that recruited 20 participants (19 males, 1 females) due to the COVID-19 pandemic.

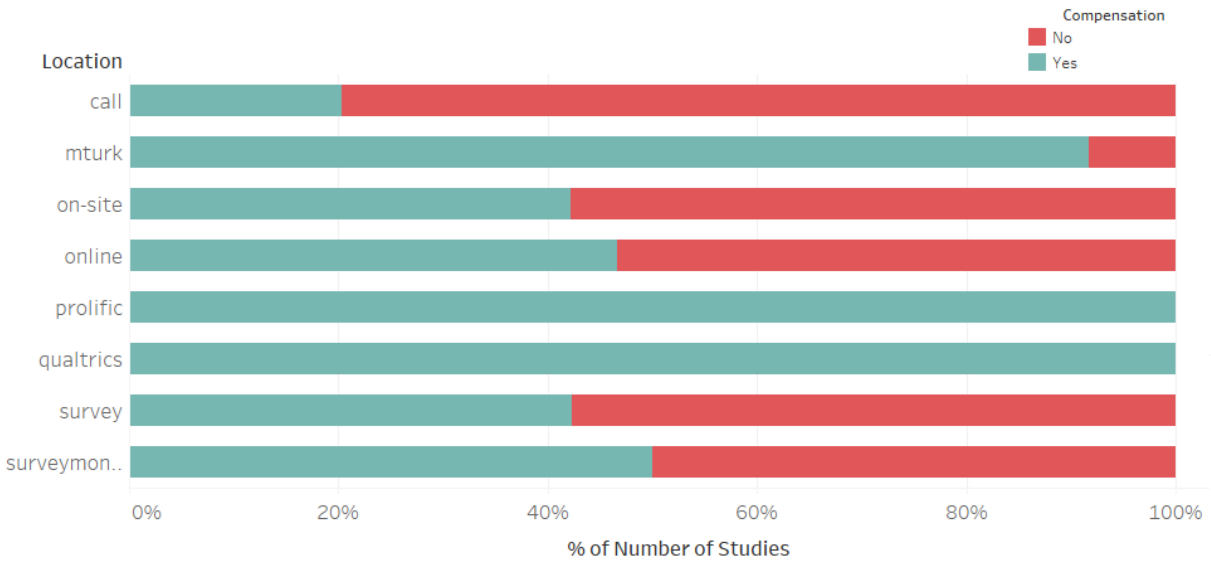

Figure 5.6: Frequency of Compensation according to percentage of Studies and the Location of Study

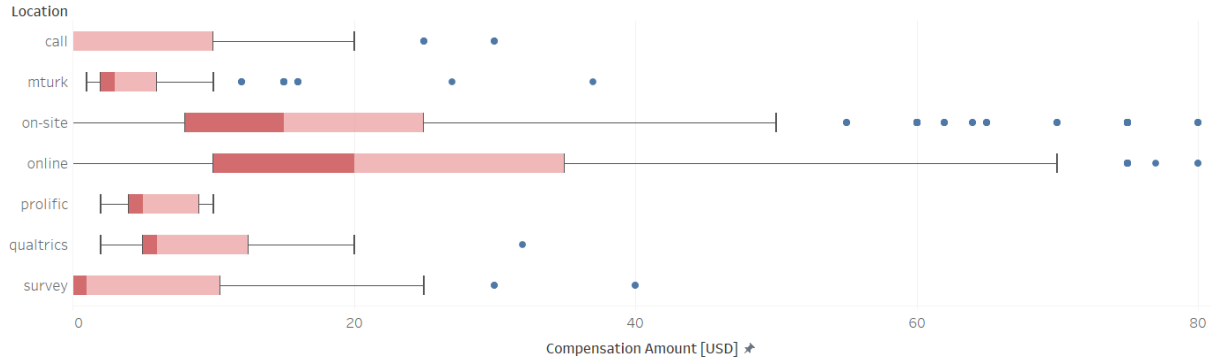

Figure 5.7: Amount of Compensation according to the Location.

As Figure 5.8 shows, the the median Participation Total Cost (includes the existence of a bonus to some Participants or of a Lottery compensation, or a coupon) is highest for Studies that used Qualtrics (med["Qualtrics"] = 1630 USD) and lowest when Studies made with Calls (med["Call"] = 0 USD). When Studies used the Amazon MTurk Prolific Crowd sourcing platforms, the median Participation Cost was between 580 to 600 USD. Studies conducted on-site have a median Participation Cost of 260 USD. An example of a Study located *On-site* with a Total Participation Cost of 260 USD, is the article of Katja Rogers et. al., from Germany, published at the CHI 2019, that recruited 26 participants (20 males, 6 females) and were compensated 10 USD.

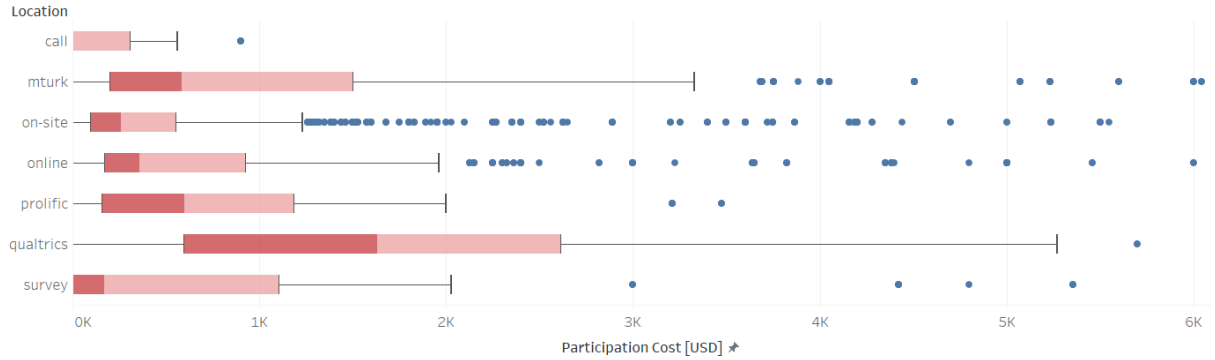

Figure 5.8: Total Participation Cost according to the Location.

5.3 Equipment Cost

For the analysis of the Equipment Cost, it is investigated whether the Equipment Cost has an impact on a Study receiving Compensation and if that Amount differ according to that cost (N = 1645). We also investigated the differences of Equipment Cost throughout the years of the CHI Conference.

Figure 5.9 shows that the median cost of Equipment is highest when No compensation is given (Med[Equipment Cost] = 880 USD), where if it was Not Indicated or it the participants were compensated in the study, the median amount was between 800 and 850 USD, respectively.

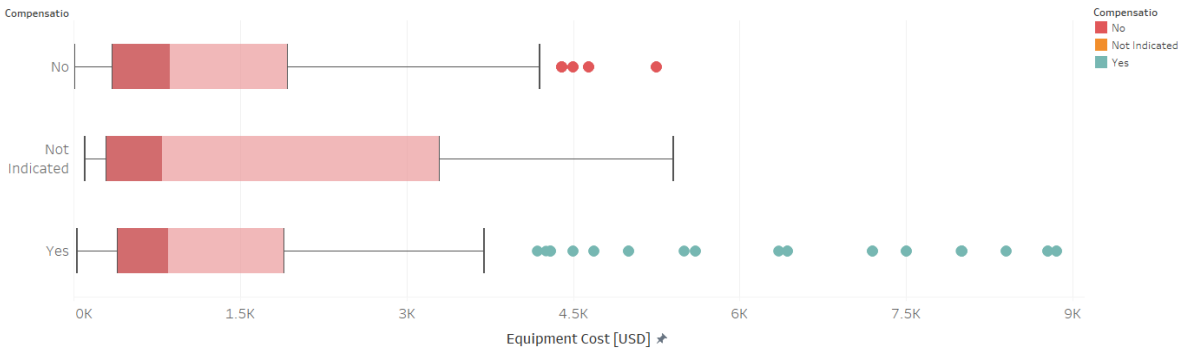

Figure 5.9: Frequency of compensation according to the Equipment Cost.

Figure 5.10 shows the Scatter plot of the Compensation Amount and the Equipment Cost. Using Pearson's correlation coefficient reveals a weak negative correlation between the Amount of Compensation and the Equipment Cost (r = -.03).

Figure 5.11 shows the evolution of the average Equipment Cost throughout the Years of the CHI proceedings. Most notably, the years where the average of the Equipment Cost was highest was between 1989 and 1995 when the values of the Equipment were 5.000 USD and 10.250 USD. From 2004 onward, the cost of the Equipment seems to stabilized between 500 USD and 2.100 USD.

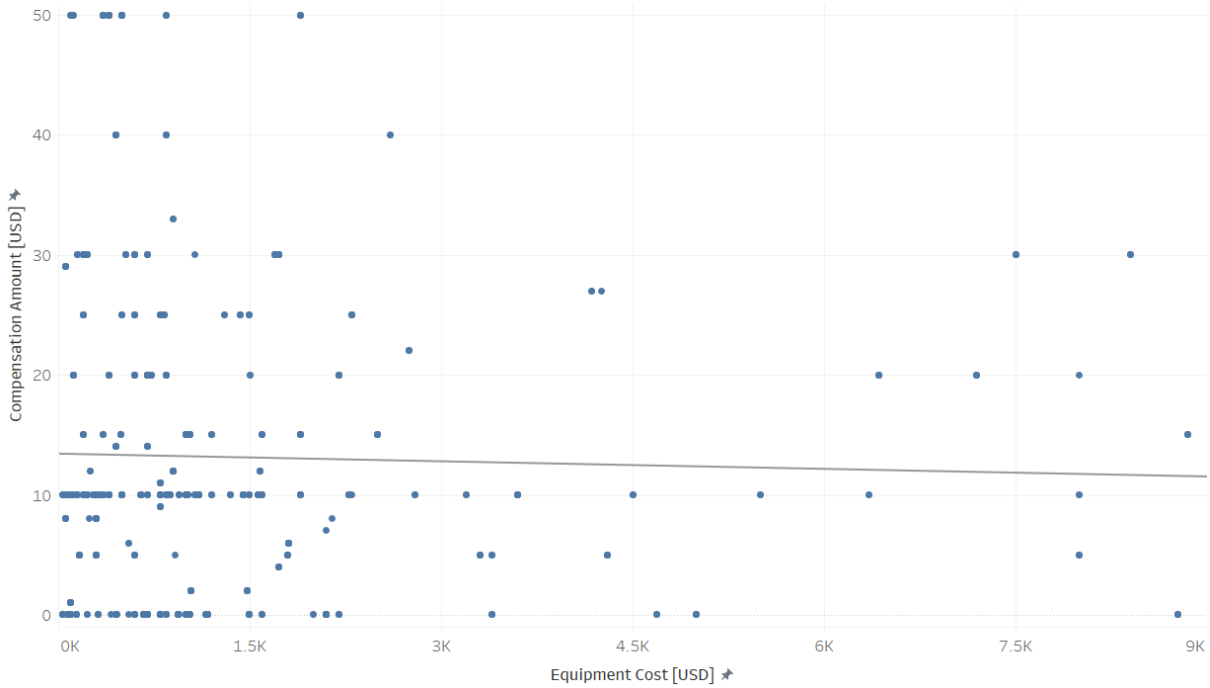

Figure 5.10: Compensation Amount and Equipment Cost.

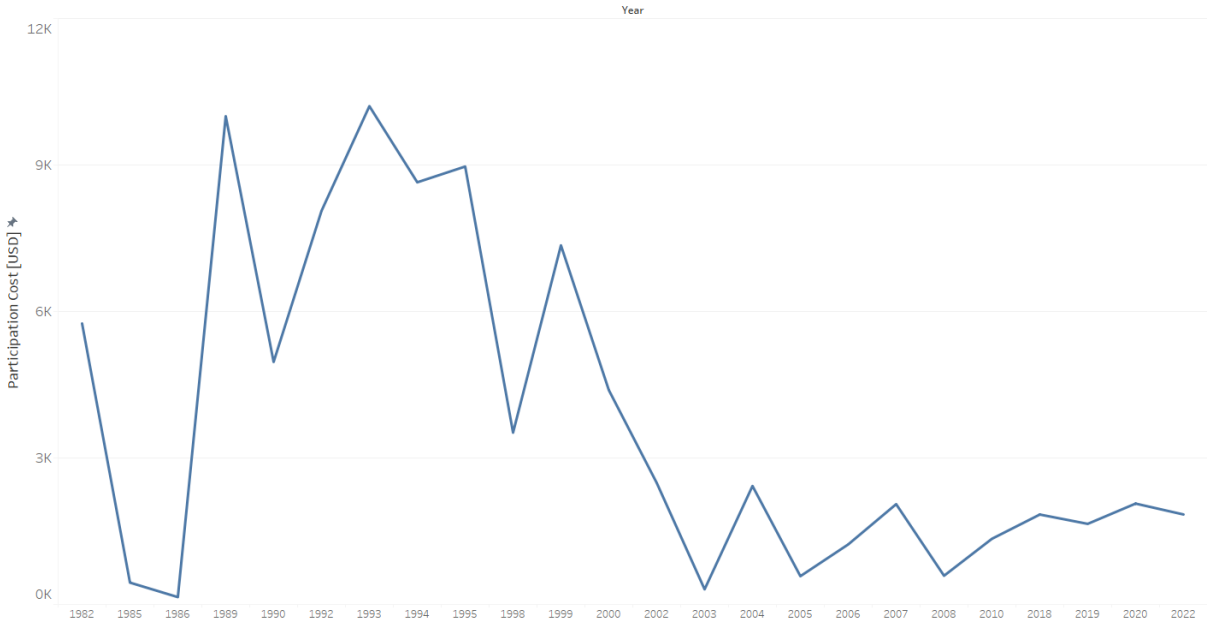

Figure 5.11: Evolution of Equipment Cost throughout the years.

5.4 Participation Cost

The next factor being analyzed is the Participation Cost. It is investigated whether the Participation Cost has an impact on the Equipment Cost (N = 1645). We also investigated the differences in Participation Cost throughout the years of the CHI Conference.

In Figure 5.12, the Scatter plot shows the Participation Cost and the Equipment Cost. Using the Pearson's correlation coefficient reveals a weak negative correlation between the Amount of Compensation and the Equipment Cost (r = -.02).

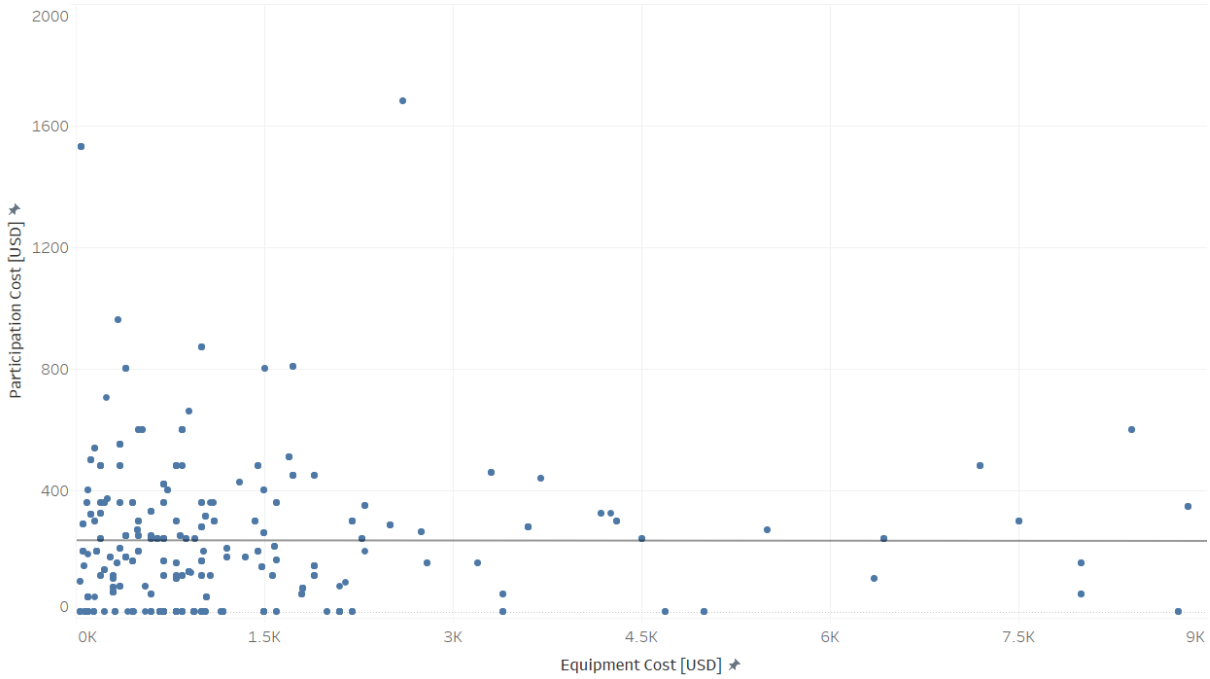

Figure 5.12: Participation Cost and Equipment Cost.

Figure 5.13 shows the evolution of the average Participation Cost throughout the Years of the CHI proceedings. Most notably, the years where the average Participation Cost was highest were between 2011 and 2022 when the values of the User Studies were 629 USD and 1.119 USD. From 1983 to 2007, the cost of Participation is at the lowest with two peaks in 1996 and 2007 at 455 and 459 USD, respectively.

5.5 Citations

The evaluation of the next factor is based on the number of citations. It was found that the number of Citations differs depending on the equipment cost (N = 1645), participation cost (N=4857) and Total Cost of the Publication (N = 6435). Based on the factors mentioned, all of these were analyzed using

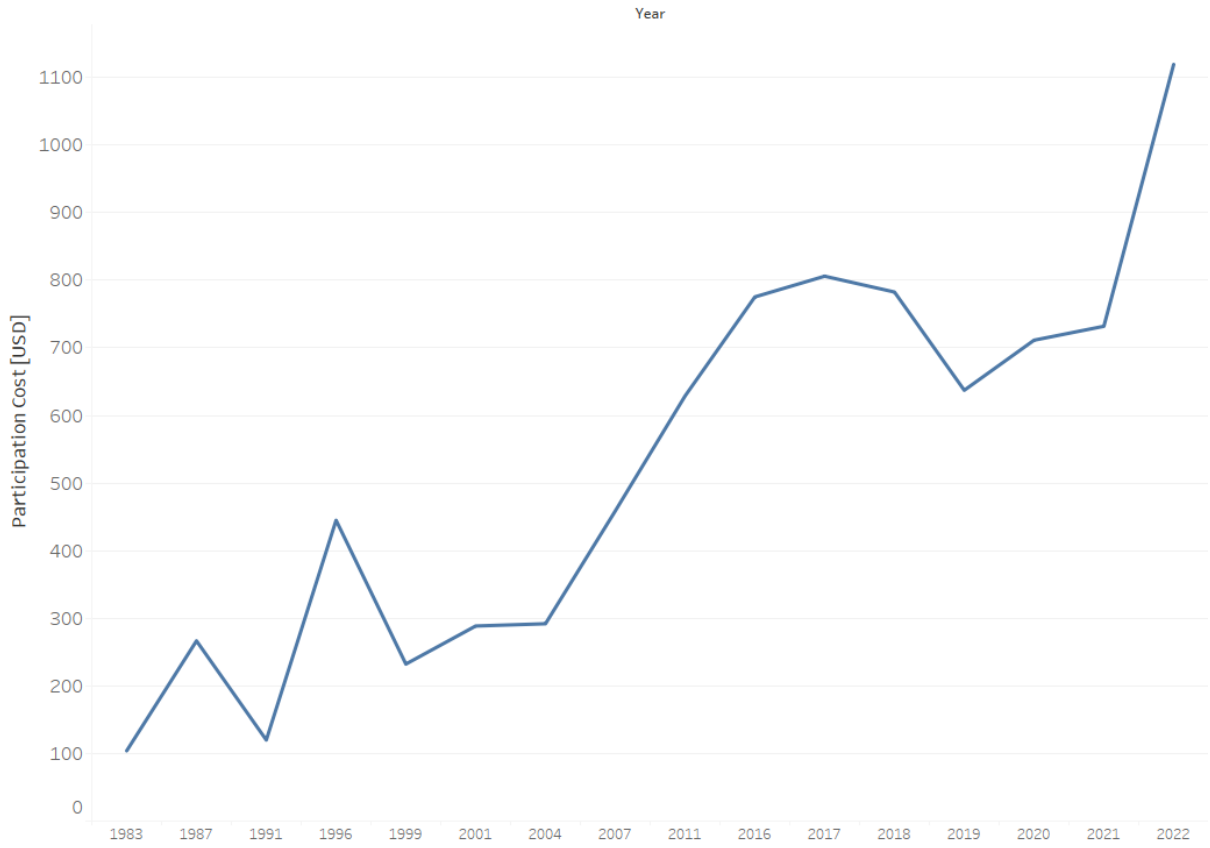

Figure 5.13: Evolution of Participation Cost throughout the years.

scatter plots. In Figure 5.14, the scatter plot shows the Equipment Costs and the number of citations. The equipment cost and number of citations do not have a strong relationship, according to Pearson's correlation coefficient (r = +.011). The area with the lowest density of marks with the Number of Citations lower than 100 and Equipment Cost lower than 3.000 USD seems to be a good place to work.

In Figure 5.15, the Scatter plot shows the Participation Cost and the Number of Citations. Using the Pearson's correlation coefficient reveals a weak positive correlation between the Participation Cost and the Number of Citations (r = +.044). It also can be seen that the area with highest density of marks are with the Number of Citations lower than 100 and Participation Cost lower than 3.000 USD.

In Figure 5.16, the Total Cost Cost and the Number of Citations are shown. Based on Pearson's correlation coefficient (r = +.052), we found a weak positive correlation between the Total Cost and the number of citations. The table shows that the areas with the highest density of marks are with a total lower than 400 USD and equipment costs lower than 1.500 USD.

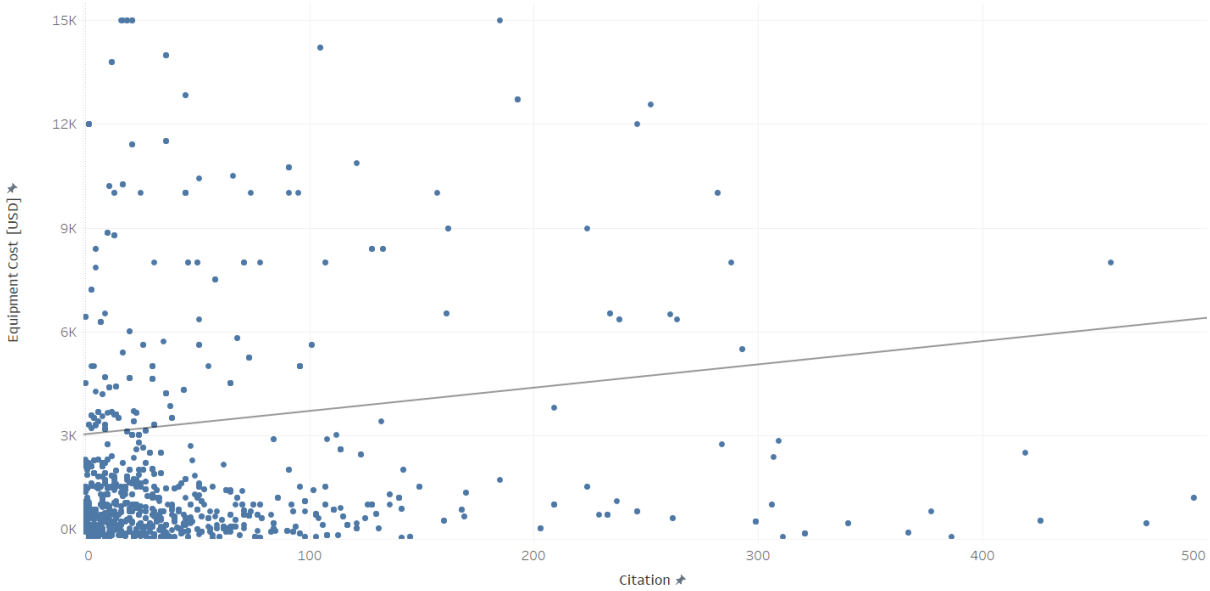

Figure 5.14: Citations and Equipment Cost.

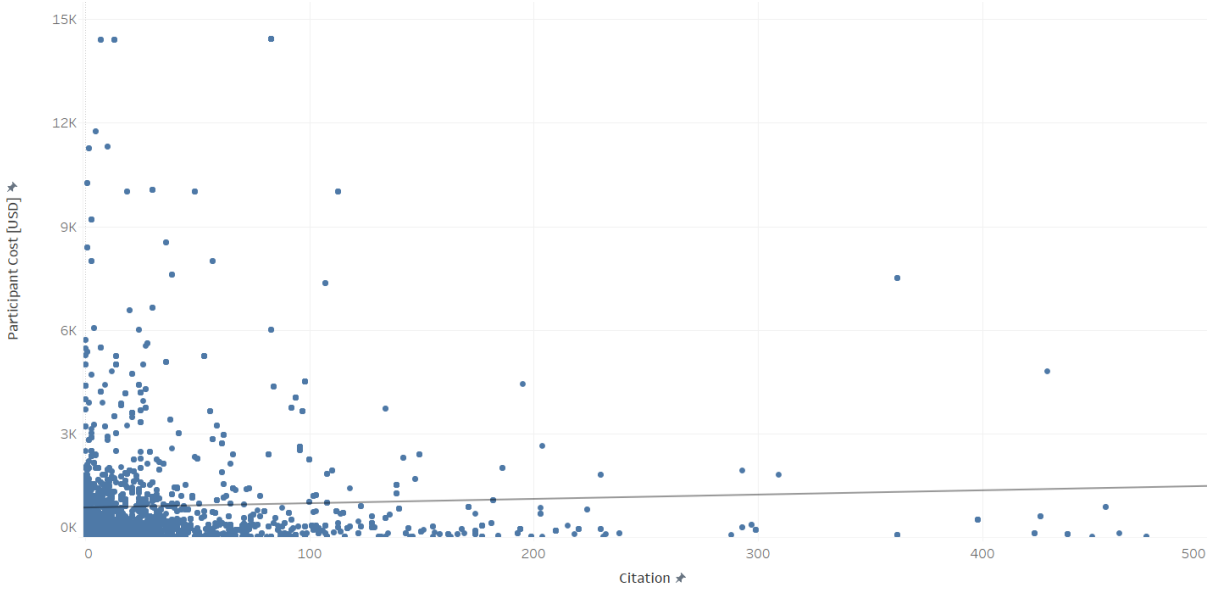

Figure 5.15: Citations and Participation Cost.

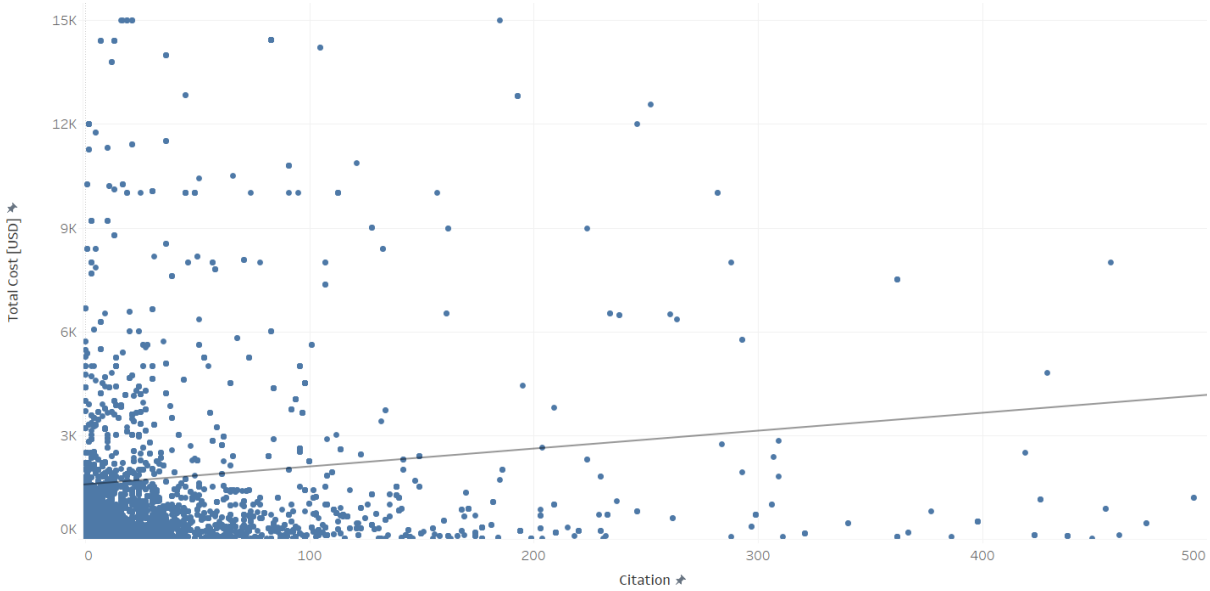

Figure 5.16: Citations and Total Cost.

5.6 Geographical Distribution

The last factor being analyzed is the Geographical Distribution. It investigated whether the Geographical Distribution has an impact on the Number of Participants, the Equipment Cost, Participation Cost and Total Cost. This will be visualized using a Map Chart. This analysis only focuses on the countries that contributed with five papers or more to the CHI conference.

In Figure 5.17, it can be seen the Global Distribution regarding the Average Number of Participants. It can be seen that North America and Europe stand out while, in Asia, China, Pakistan, India, Saudi Arabia, Japan, Malaysia, Bangladesh, Taiwan and South Korea make appearances on the Map. In South America, only Brazil and Ecuador meet the criteria of having five papers published. Representing the African Countries, we can see Egypt, Namibia, South Africa and Kenya. Australia and New Zealand are constituting Oceania. The Countries with the highest Average Number of Participants are Pakistan, Japan and USA, with 1559, 793 and 330 USD, respectively.

In figure 5.18 it displays the Global Distribution regarding if a Participant receives Compensation or not. From the Bar Chart, we can grasp that the On-site is the most frequent location of studies in most countries ranging between 44,44% to 81.92% ,except in India and Portugal where the study have a higher frequent of being online with 58.62% and 50%, respectively. Pakistan was the country that have a higher frequency of using Calls in a Study. Regarding the crowd sourcing websites, Israel (18.52%), Spain(7.14%) and Switzerland (1.59%) are the country with highest frequency in MTurk, Prolific and Qualtrics, in that order.

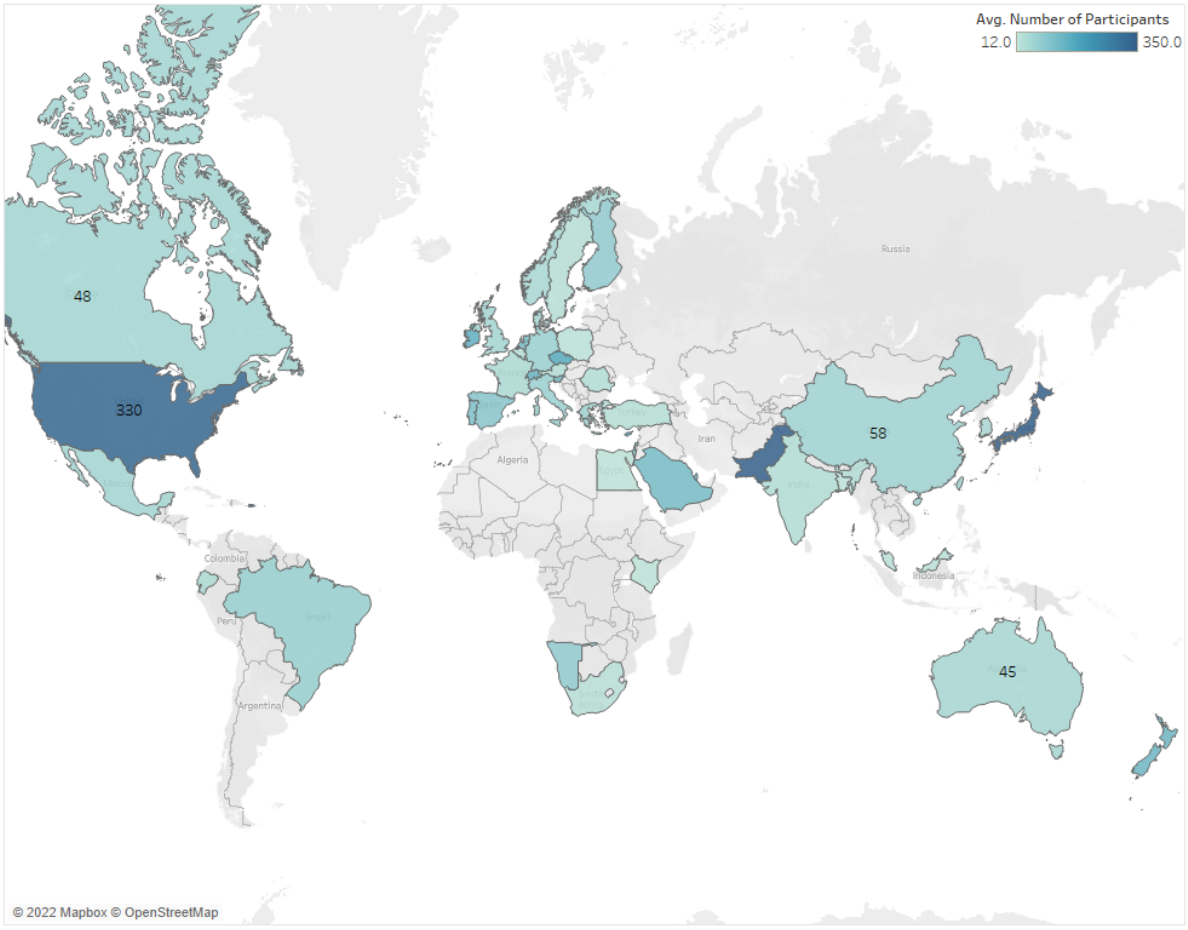

Figure 5.17: Geographical Distribution of CHI regarding Number of Participants.

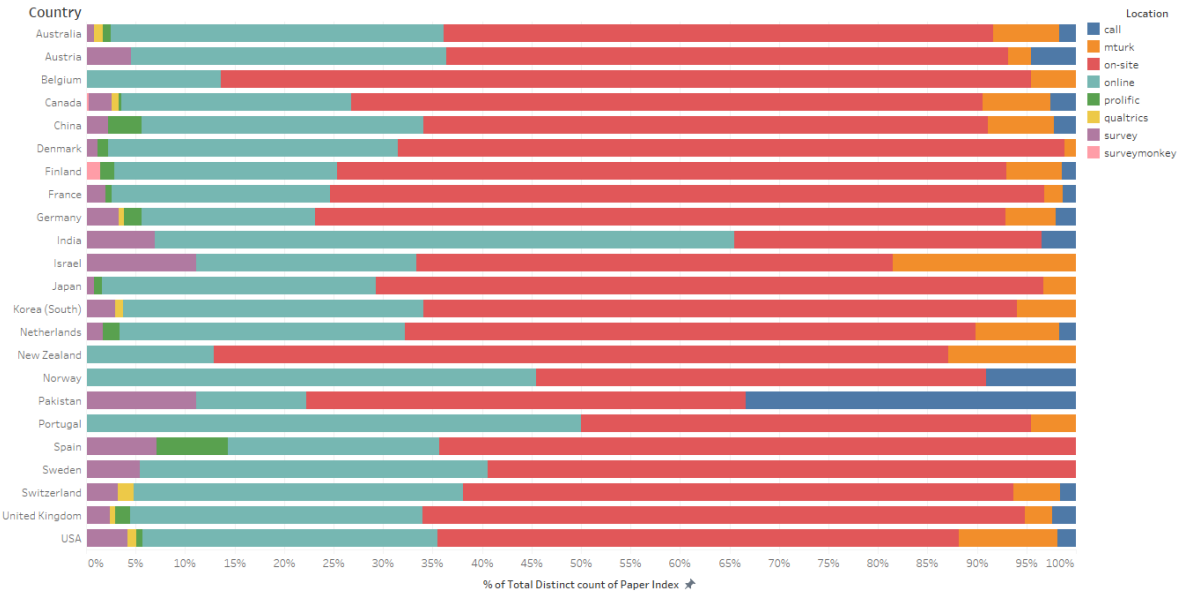

Figure 5.18: Frequency of Location according to the Top 20 Countries by number of Papers published.

In Figure 5.19, it can be seen the Global Distribution regarding if a Participant receives Compensation or not. From the Bar Chart, we can grasp that the Country where the Participants were compensated more frequently was South Korea (47.03%), followed by the USA (40.77%) and Singapore (40.30%). The countries where the frequency of compensation is lowest in Austria (56.67%), Sweden (50.47%) and France (49.18%). Denmark (37.32%), India (32.56%) and Belgium (31.25%) are the countries with higher percentages where Compensation was not indicated.

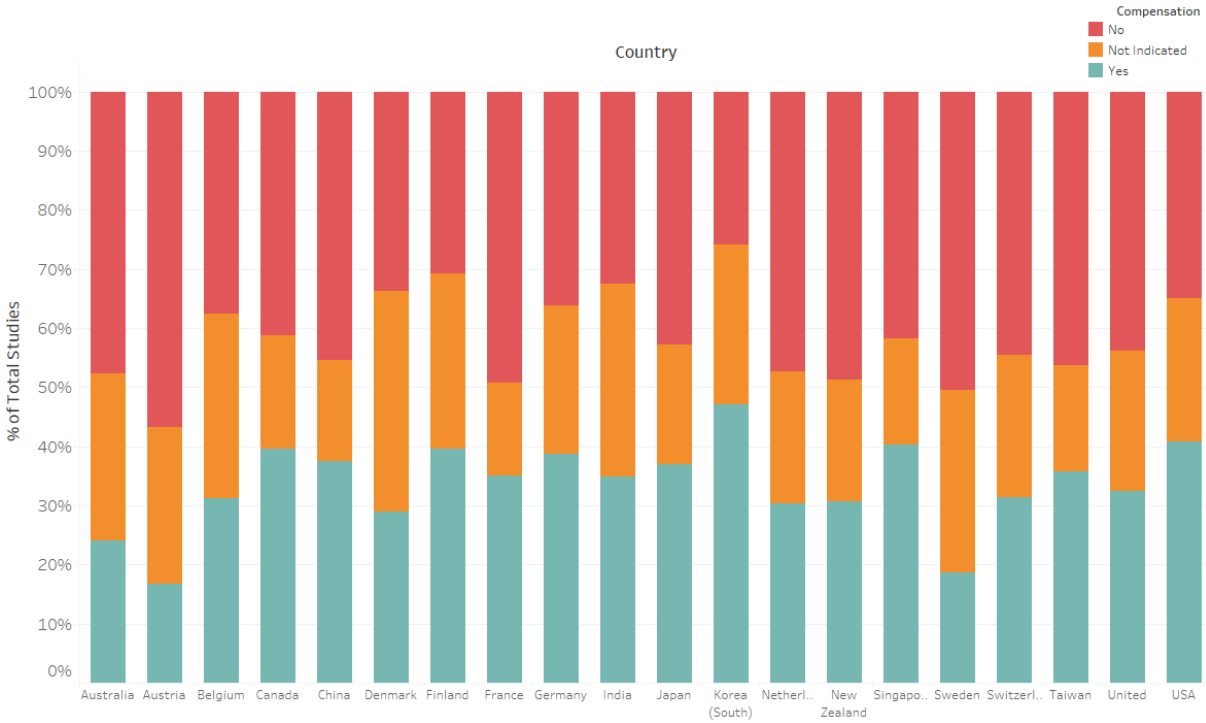

Figure 5.19: Frequency of Compensation according to the Top 20 Countries by number of Papers published.

In Figure 5.20, it can be seen the Global Distribution regarding the Average Equipment Cost. It can be seen that North America and Europe stand out while, in Asia, China, Pakistan, India, Saudi Arabia, Japan, Malaysia, Taiwan and South Korea make appearances on the Map. In South America, only Brazil and Ecuador meet the criteria of having five papers published. Representing the African Countries, we can see Egypt, Namibia, South Africa and Kenya. Australia and New Zealand are the representatives of Oceania. The Countries with the highest Average Equipment Cost are Austria, Finland and Australia, with 6000, 5000 and 4823 USD, respectively.

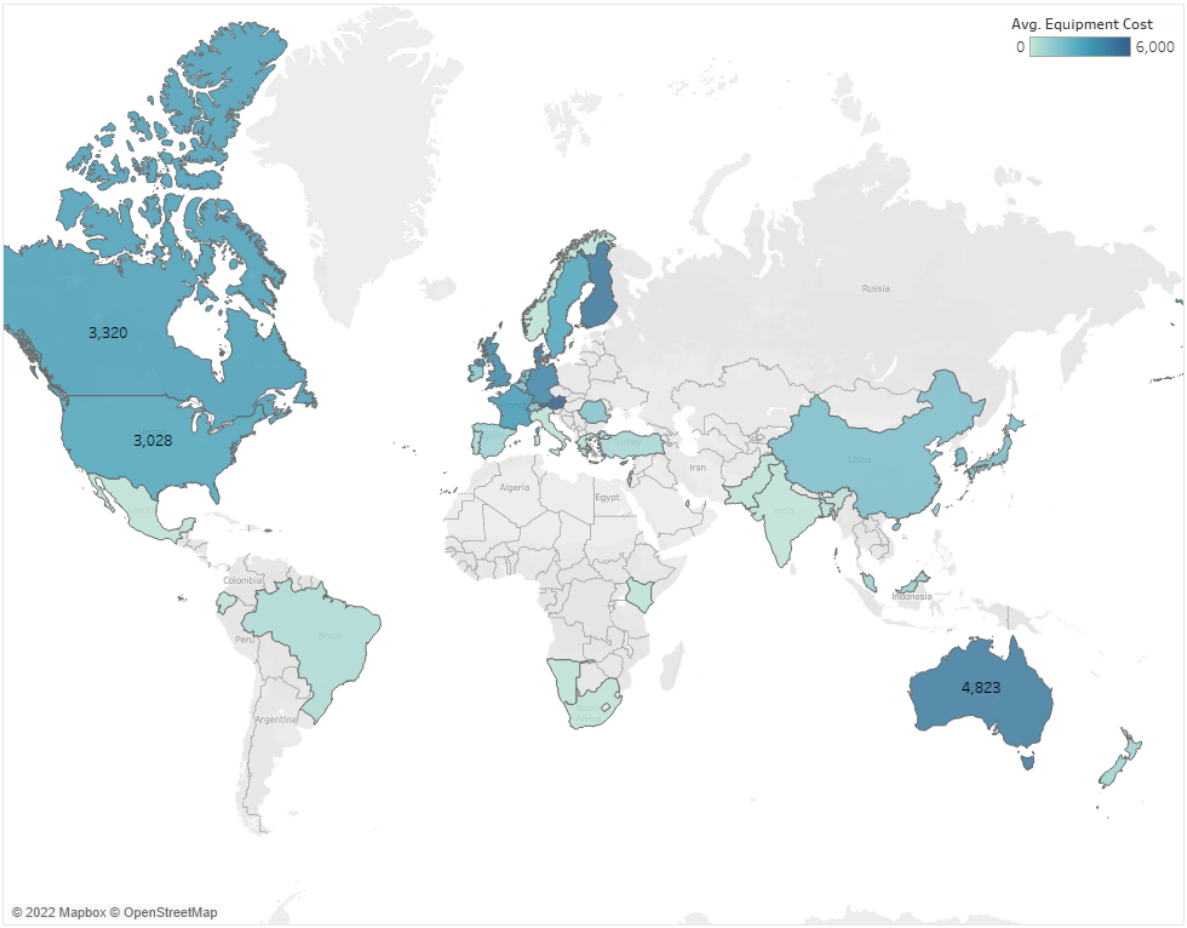

Figure 5.20: Geographical Distribution of CHI regarding Equipment Cost.

In Figure 5.21, it can be seen that the distribution of the average Participation Cost is uneven. It can be seen that the numbers in North America and Europe are higher than Asia, with China, Pakistan, India, Israel, Qatar, Japan, Malaysia, Taiwan, and South Korea all making appearances. In South America, Brazil and Ecuador only have four papers published. We can see Namibia, South Africa, and Kenya here. Australia and New Zealand are the representatives of Oceania. The countries with the highest average participation cost are Israel, the Netherlands, and Switzerland. Their average participation cost is 7856 USD, 3991 USD, and 1820 USD, respectively.

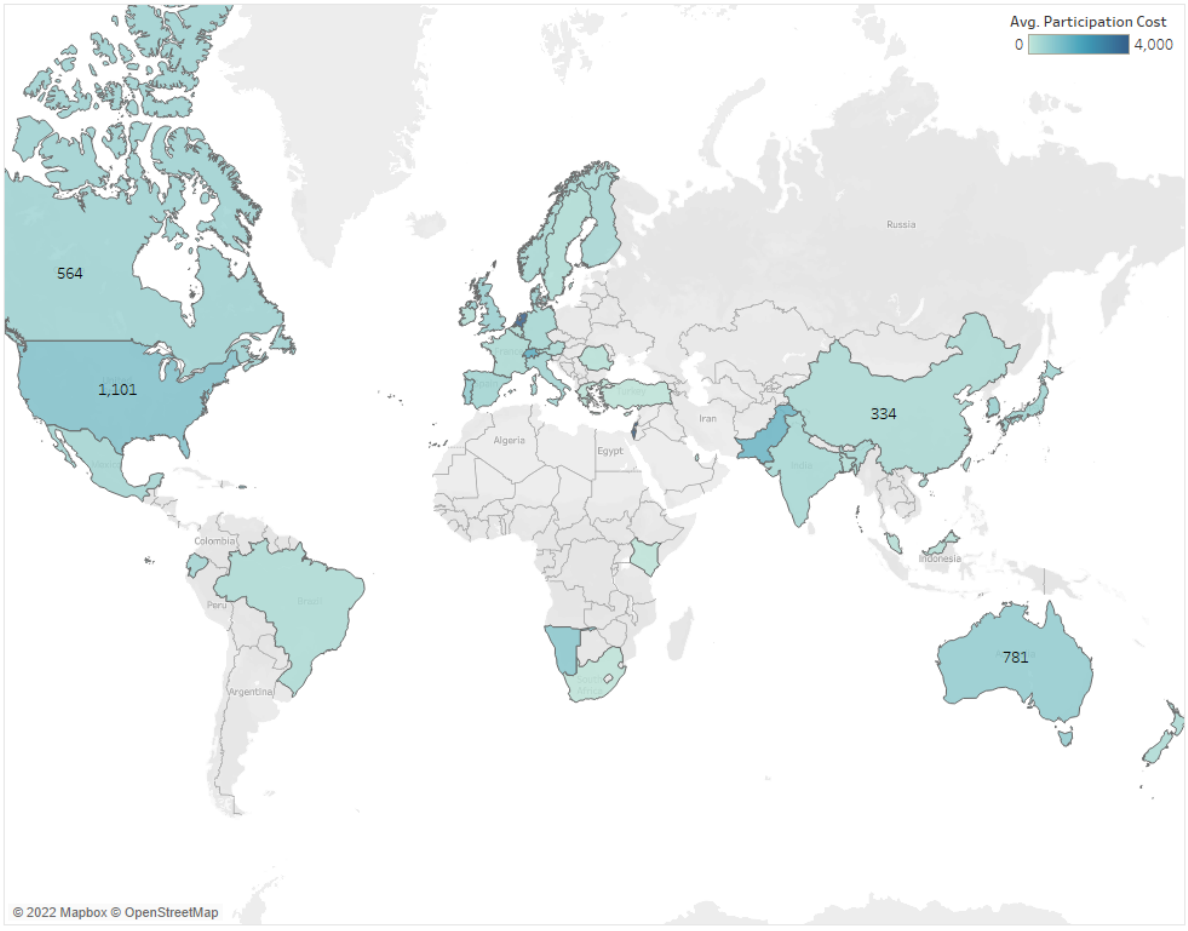

Figure 5.21: Geographical Distribution of CHI regarding Participation Cost.

In Figure 5.22, it can be seen the Global Distribution regarding the Average Total Cost. It can be seen the North America and Europe standing out while, in Asia, China, Pakistan, India, Israel, Qatar, Japan, Malasya, Taiwan and South Korea make appearances in the Map. In the South America only Brazil and Ecuador meet the criteria of having five papers published. Representing the African Country, we can see Namibia, South Africa and Kenya. Australia and New Zealand are the representatives of Oceania. The Countries with highest Average Total Cost are Israel, Netherlands and Switzerland with 6351, 3771 and 3669 USD, respectively.

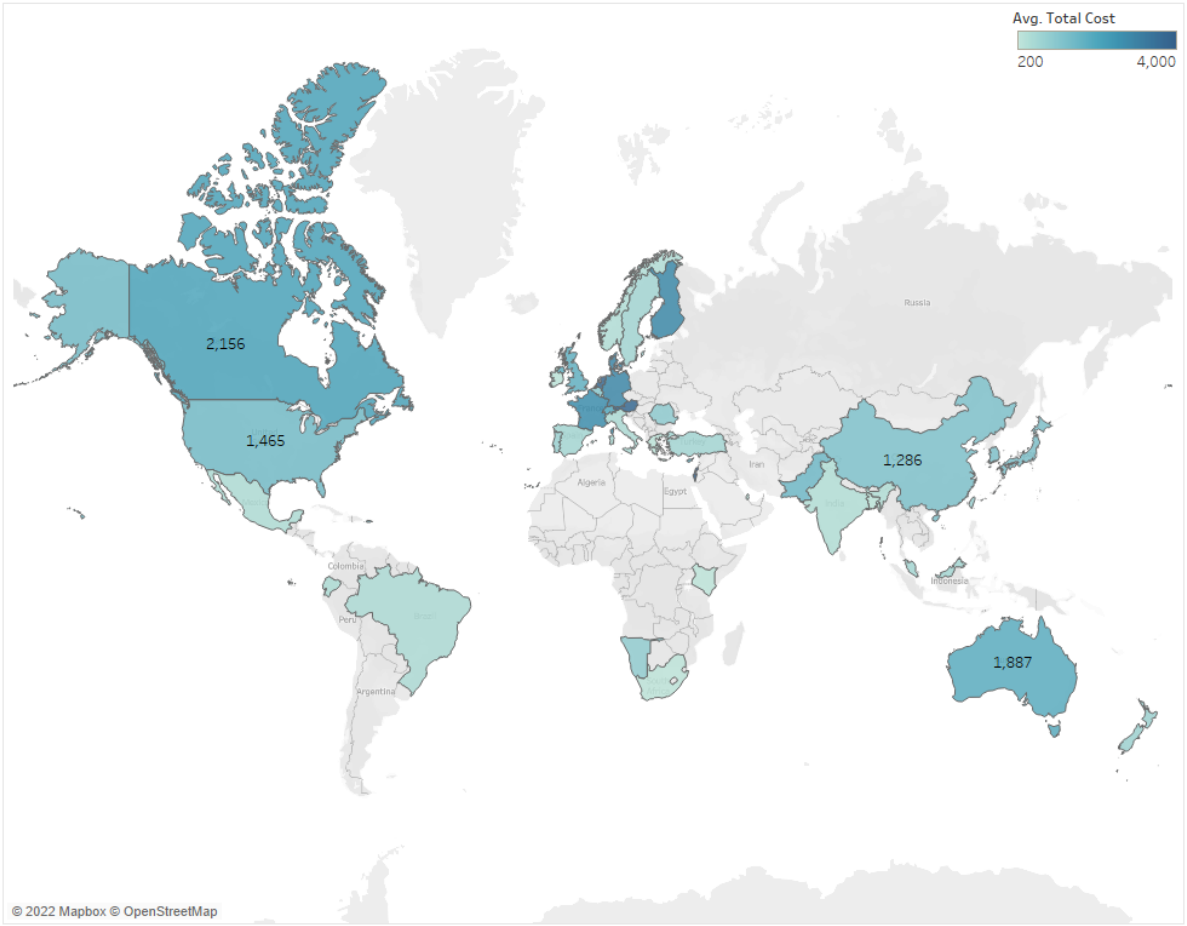

Figure 5.22: Geographical Distribution of CHI regarding Total Cost of Article.

6

Discussion

Contents

In the following chapter, the we answer our four research questions, summarizing the major findings attained. For this discussion, we will start by interpreting the findings according to data collected and discuss what has been done in the world of HCI Research in terms of Participation and Equipment Cost in order to answer the Research Questions we proposed, which is our main goal. Secondly we will examine the results of the Geographical Distribution of the Participation and Equipment Cost and lastly also compare these quantification's of the articles with the Number of Citations.

6.1 Quantifying the costs of HCI research

To quantify the costs of researching HCI, it was found that the Total Cost differs for the Number of Participant, Location of the Study, Compensation, Amount of Compensation and Equipment Cost. First, was it was investigated the several factors to find a explanation for the fact that participants were compensated more frequently on crowd sourcing websites (Amazon MTurk, Prolific and Qualtrics). In the second place, several factors were analyzed to find explanations for the fact that participants were compensated with the highest amount in online and on-site studies and the lowest amount in Calls or Surveys and in crowd sourcing websites (Qualtrics, Prolific and MTurk). Finally we will give an explanation on why the Equipment Cost has a weak negative correlation with the Compensation Amount and analyze the evolution of the Equipment Cost and the Participation Cost from 1983-2022.

First off, it is not unexpected that the study's location affects the number of participants. Kittur et al. at [66] concluded that using Micro-Task markets, such as Amazon MTurk in the case of the authors, can be used to recruit and conduct a large number of participants in a very short time. On crowd sourcing websites, Workers get paid for every Task conducted, or in the case of MTurk, for every HIT [67]. Consequentially, it is noticeable that the frequency of compensation is highest for participants recruited on the crowd sourcing website. Furthermore, the Survey has the second lowest frequency of compensation, but it was found the median number of Participants doesn't differ with the Crowd sourcing websites, indicating that this Location by itself is an not explanation for the differences in the frequency of compensation. Lastly, the frequency of compensation in a Study by Calling the participants is the lowest. This can be hypothesized to being more difficult to find a large number of motivated participants.

Concerning the Compensation Amount, it was found that the amount differs with the Number of Participants, Location and Equipment Cost.

When more individuals participate, there is less money left over for each person to get compensation, which explains why there is a negative correlation between the number of participants and the amount of compensation. The results demonstrate that sample size should be taken into consideration as a variable that might account for variations in the amount of compensation.

Since participants recruited online and on-site received the highest median amount of compensation

and participants recruited via Amazon MTurk, Prolific and Qualtrics were compensated with the lowest median amount, while having the highest medium Participation Cost, the Location is not the only variable that could contribute for variations in the amount of compensation and frequency. Kittur et al. at [66] have already demonstrated that workers hired through Amazon MTurk typically receive a low incentive. Indeed this is also proven at the CHI Conference. The increase in the Participation Cost throughout the years of the CHI conference can be explained due to the boom of Digital age platforms providing researchers with the ability to outsource portions of their work, the User Studies, but also to a relatively low-cost online labour force comprised of humans [67].

The positive correlation between the number of participants and the Equipment Cost can be explained by the fact that if the value of the Apparatus is high, the more novelty the equipment is bringing a large number of motivated participants.

Although having more Participants, there exists a negative correlation between the Amount of Compensation with the Equipment Cost and between the Participation Cost and the Equipment Cost. Both of these correlations may be explained by the fact that when more people participate, there are fewer funds left over for each subject out of the amount that was spent for acquiring the equipment and apparatus. The fact that there is just a weak correlation suggests that one of the primary factors that could account for differences in the equipment costs is not the number of participants, the amount of compensation, or the Participation Cost.

The decrease of the Equipment Cost throughout the years of the CHI conference can be explained due to in the earlier years of the Conference, a Computer or the Apparatus that was used is expensive and scarce, gradually becoming more common, faster and cheaper due to the advancements of Transistors [68].

6.2 Citations

Concerning the Number of Citations, it was found that the number of citations differed with the Equipment Cost, Participation Cost and Total Cost.

The positive correlation between the number of Citations and the Equipment Cost can be explained by the fact that if the value of the Apparatus is high, the more novelty the equipment and the more studies with the same equipment or with a similar one, citing the original one. In the same manner, there also exists a positive correlation between the Number of Citation and the Participation Cost and between the Number of Citation and the Total Cost of the Article, but all of these correlations are weak which indicates that one of the main factors that could explain the differences in the amount of compensation. A limitation of the dataset is many papers published in 2022 are still too recent to have already received citations.

Saeed Roshani at [37] argued that the Area of Computer Science has a high correlation between funding for research and studies being cited at least once. This did not prove for CHI conference.

6.3 Geographical Distribution

In this section, we investigated the Geographical Distribution regarding the Number of Participants, Frequency of Compensation, Participation Costs and Total Cost.

It can be observed on every map that the USA, UK, Canada, The Netherlands, Australia, New Zealand, Switzerland, France, Germany and a few other European countries stand out. In the Asian Continent, China, Pakistan, India, Saudi Arabia, Japan, Malaysia, Bangladesh, Taiwan and South Korea. But entire continents, such as South America and Africa are out of proportion compared with the percentage of countries in the other continents. Relative to the Participation Cost and the Total Cost, the Countries with the highest Average Participation Cost and Total Cost are Israel, Netherlands and Switzerland. In the case of the Equipment Cost, the countries standing out are Austria, Finland and Austria. These costs can all be explained due to all of those countries being Industrialized and Rich [2].

Andrea Mannocci et al. [24] demonstrated in the case of IJHCS and CHI that the knowledge generated, regarding the publications being cited in these conferences, is confined to rather a small number of countries in North America, Europe, Oceania, and the Far East, evidencing that there is not an impact on a larger scale on the geographical diversity of the contributions at CHI. This is also the case for the metrics that we analysed, more specifically, Participation Cost and Equipment Cost.

7

Conclusion

Contents

Our goal with this Thesis was to quantify the cost of conducting research in Human-Computer Interaction at the premier conference for this field, the CHI Conference. We presented an analysis of the Participation Cost and the Equipment Cost and their differences according to many factors, e.g. the location where the study occurred, and presented several visualizations to demonstrate the findings. We also presented with this work, the international representativeness of the Participation Cost, the Equipment Cost and the Number of Participants.

Our findings revealed that the frequency of Compensation, Participation Cost, and Equipment Cost differs based on the location where the study occurred and the Country, proving that there is not much geographical diversity in the CHI conference. Of these factors, the Location of the study has proven to be one of the main influencing factors since it also explains the higher frequency of compensation for MTurk, Qualtrics and Prolific. These results can be explained due to the straightforwardness of recruiting a large number of participants in a very short time. It was found that publications that used crowd-sourcing websites spent more in compensating their participants than on-site but higher amounts were offered for studies that were made on the field or online.

To answer the Hypothesis Question **H2** in Section 1.1, we analysed the correlation between the Participation Cost and Equipment Cost. We conclude that there is a trade-off between acquiring the Apparatus and the compensation given to the participants that can be hypothesized by the fact that a certain amount of the money received for the research was used for the Apparatus, therefore less is left for each individual when more people participate. In the same manner, but to answer the Hypothesis Question **H3**, we found a weak positive correlation between the number of Citation and the Equipment cost and between the Number of Citations and the Participation Cost, meaning that these factors are not one of the main influencing factors.

7.1 Contributions

With this thesis, we presented the design and implementation of a Scraper and a Crawler for retrieving the full-text PDF articles of the CHI conference. A systematic literature review of all articles scraped was conducted, where the data was extracted manually to develop a dataset that all annotated articles from the 1983-2022 CHI proceedings.

We also analyzed the metrics extracted and presented visualizations to help understand what has been done in the world of HCI Research, specifically in the CHI conference, in terms of Equipment Cost and Participation cost. Our findings also provide a geographic representation of the research costs and their impact on the number of citations.

All the code for performing the Scraping, the PDF extraction as well as for collecting the other previously mentioned data can be found at
https://github.com/miguelsequeiradias/Quantifying-the-Cost-of-conducting-HCI-research.

7.2 Limitations

This Thesis's major limitation is that its conclusions are dependent on what the authors wrote. For instance, just because incentives were not mentioned does not mean that pay was not provided, and just because the apparatus was not detailed does not mean that it was not any equipment used. There were some cases of the Equipment not being detailed enough to find out the commercial value of the setup used in the Article.

Secondly, many of the quantities obtained in terms of compensation were not normalized using the hourly wage of the source country since the duration of the research was not recorded. This limitation of this Thesis because Hitlin at [67] pointed out that most tasks on Amazon MTurk have a very short duration and Jenny Reinhard at [64] proved for CHI 2019, there is a Positive correlation between the study duration and the amount of compensation.

Additionally, the currency rates may have changed throughout the two months of data collection. Since the majority of the amounts were given in USD, this restriction is probably not particularly significant.

Lastly, a limitation of the this Thesis was the cross-ref of the Cost of the Equipment was not all done at the same website or the same database.

7.3 Future Work

The data set can be used to provide insights about current practices regarding the type of equipment that was used by analyzing the Equipment Name, in addition to examining the frequency and amount of compensation and the Equipment Cost. In addition, the data gathering makes it possible to look into other factors not included in this thesis, including participant gender, affiliation, and equipment name. With this method, additional explanations for the outcomes might be found, opening up a wider perspective on current practices.

Machine learning techniques can be used for both keyword extraction and classification to overcome the limitations of approaches used to extract Equipment Names, Amount of Compensation and even Participation costs. To extract more keywords with the same level of information, it is ideal to consider larger sections of the paper rather, if not even the entire article. This is because we only looked for chapter headings that may contain the relevant keyword we are looking for.

To compare the results of this study with the results, it is worth looking at other conferences that have used the same source code in future research. It may be possible to identify boundaries with other research areas or to identify trends.

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