Comparing Haptic Application Design Communities: Characterizing Differences and Similarities for Future Design Knowledge Sharing

by

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Comparing Haptic Application Design Communities: Characterizing Differences and Similarities for Future Design Knowledge Sharing

submitted by Matthew (Jungho) Chun in partial fulfillment of the requirements for the degree of Master of Science in Computer Science

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Abstract

Haptic technology has increasingly blended digital and physical world elements to create intuitive interactions in areas such as affective computing, VR/AR, video games, education and various other domains.

However, we posit that the emergence of best processes for designing impactful haptic applications has been hindered by a lack of shared understanding of the technical and conceptual design knowledge involved in developing meaningful haptic experiences.

With over 27 years of diverse haptic literature, we have an opportunity to verify our supposition by characterizing community design practices in their similarities/differences which can be used to highlight areas of design expertise and gaps that other communities can help improve/complete. In future work, these characterizations can be further analyzed and integrated to help formulate effective haptic application design processes which could lead towards new or improved haptic application experiences.

We conducted a scoping literature review that provided initial characterizations of community haptic application design practices, in order to lay the foundations for future cross-fertilization of design knowledge.

Lay Summary

Haptic technology and its ability to recreate various types of physical sensations can enable the physicality missing in applications such as affective computing and virtual reality immersion.

But the impact of haptic technology has been small. Its use in mainstream applications has been relegated towards simple vibrations in smartphones and video game controllers. This small impact could be due to a lack of coordination between notable application design communities of the important technical and conceptual knowledge required to create meaningful haptic applications.

We used a scoping literature review to characterize, analyze, and compare notable haptic application design communities' effective design practices regarding the conceptual and technical aspects of designing haptic applications. This was done in order to support future design knowledge sharing that could serve to improve the overall process of haptic application design.

Preface

This thesis was written based on the study approved by the UBC Behavioural Research Ethics Board (certificate number H13-01620). This thesis represents original work that provides structured synthesis and analysis of multiple publications using a scoping literature review. Prof. Karon MacLean assisted in framing and editing sections of this thesis. SPIN (Sensory Perception and Interaction) lab members contributed feedback on various thesis components such as the methodology and the overall motivations of the thesis.

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Acknowledgements

To start, I would like to thank my supervisor, Karon MacLean, and all of my fellow Sensory Perception and Interaction (SPIN) lab members for their longtime support. All of these individuals imparted excellent advice that taught me how to be better in communicating and framing my ideas, and to always ensure that the best approach was being taken in my research. More importantly, these individuals were a source of great motivation, and kept me going even when I hit some metaphorical walls. My research skills have no doubt been sharpened by all of SPIN, but I will aspire to grow further as a researcher to match their impressive qualities. I would also like to thank my second reader, Tamara Munzner, for graciously offering her time and excellent insights to improve my thesis. I would like to also thank the Designing for People (DFP) staff such as Jocelyn McKay who also provided excellent advice/resources for my scoping literature review. Finally, I would like to thank my family, friends, and fellow graduate students who have provided excellent morale support and advice to keep me going through these years.

Chapter 1

Introduction

Haptics, the field of technology and research of recreating physical sensations, could be the missing key in conveying the physicality of natural user applications such as virtual reality and affective computing.

However, the technology's impact on mainstream user application experiences can be considered minimal. Mainstream haptic user applications have largely been relegated towards simple vibrations in smartphones, wearable devices, and video game controllers.

This minimal impact could be due to the unique challenges of haptic application design and a slow pace of developing best practices and support systems to address them. We define haptic application design to be the rationale, descriptions, and methods of how haptic technology is designed towards a targeted human activity.

Fortunately, two notable communities have been involved in producing over 27 years of haptic research that may contain helpful knowledge to maximize the design of haptic application experiences. The goal of this thesis is to characterize the differences/similarities in design practice between these communities as a means of understanding whether there will be benefit in establishing greater intermixing of their knowledge and methods.

1.1 Motivation

1.1.1 Research Goal

As Figure 1.1 indicates, we will codify two notable communities ostensibly covering different types of haptic application design.

HCI Community - HCI, shorthand for human computer interaction, is a relatively large research community focused on different perspectives of human interactions with computational technology, spanning a large diversity of methods, purposes and types of technologies. Haptics-based interaction design research may comprise a small but growing fraction of this community's overall attention. In terms of scale, the largest HCI conference CHI (Conference on Human Factors in Computing Systems) featured 666 publications in 2018, the most recent year included in this study.

Haptics Community - The Haptics community, true to its name, covers haptic technology related research, such as the engineering or psychophysical aspects of haptic technology. The notion of design within this community maybe different from the HCI community and may cover only a small portion of the community's research output. In terms of scale, the largest Haptics conference HS (Haptics Symposium) featured 57 publications in 2018.

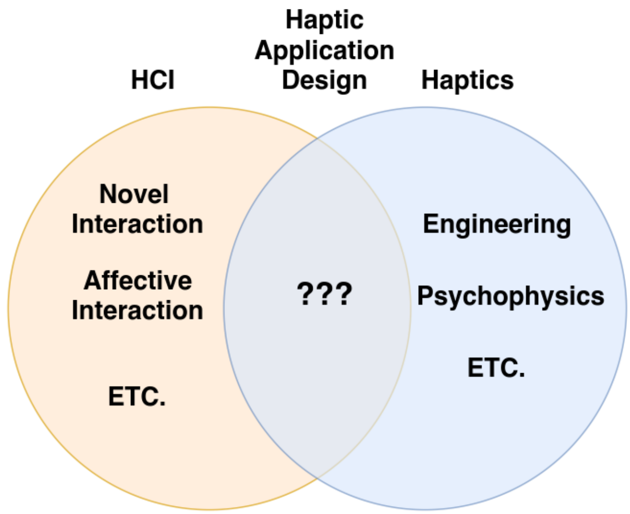

Figure 1.1: The two communities of interest in our study. What areas of research among them describe haptic application design?

Our research goal is to **discover the different/similar community design practices used to design haptic applications**. Specifically, we wish to gain insights into design practices regarding ...

- **Technical Design -** These are details related to haptic technology and other relevant details needed to implement a haptic application.
- **Experience Design -** These are details related to targeted user experiences that can drive the requirements for a haptic application design.
- **Design Methods -** These are details regarding the specific methods used in the technical and experience design of haptic applications.

We argue that each area is applicable to the haptic application design approaches of both communities. We wish to understand the different/similar practices in these areas in order to help lay the foundations for **cross-fertilization** of design knowledge.

1.1.2 Opportunity for Knowledge Sharing

We define **cross-fertilization** as the act of knowledge sharing between different research communities in order to solve common problems or to create new innovative experiences. The benefits of cross-fertilization have been seen in many research domains.

For example, Computer Scientists have been inspired by the Psychology and Statistics communities to create compelling artificial intelligence applications [1]. HCI researchers have adopted social science practices such as field data gathering techniques in order to capture the reality of in-situ human behavior [2]. Haptics researchers have leveraged the psychophysical and biomechanical knowledge of other domains to inform practical haptic technology decisions [3].

These examples show that cross-fertilization have shown tangible benefits in the understanding and development of impactful experiences. Thus, we believe that such knowledge sharing could be helpful for HCI and Haptics researchers designing haptic applications.

For example, if one community has faced problems in a specific design area, they could adopt different design practices from a community that has solved these problems. If both communities practice similar design methods, these can be compared to strengthen the overall efficacy of the design methods.

But before any potential cross-fertilization can be conducted, it is important to understand the current nature of haptic application design practices among the HCI and Haptics communities.

1.2 Research Questions and Methodological Approach

1.2.1 Research Questions

The cross-disciplinary nature of our research created a challenge in the formulation of appropriate research questions. In particular, it was difficult to determine the common grounds that could fairly compare the HCI and Haptics communities respective haptic application design approaches.

Thus, to set the direction for our primary study, we conducted an informal analysis on a set of potential haptic application design papers (not based on our final methodology/sample) to help develop our research direction.

These papers were chosen through a variety of means including personal knowledge and reviewing the publications from well-known haptic research venues. More specifically, these papers came from an informal literature review that looked at notable community venues within our years of interest, covering different size scales and haptic knowledge contributions (eg. novel engineering to support new types of interactions). Please refer to Chapter 3 (Approach) for further clarity on our informal analysis process.

We derived the following focal points (concepts related to our research goals) and their associated research questions. These questions were chosen as they could produce interesting data and implications for community haptic application design practices.

Focal Point 1 - Design Energy Distribution

RQ1(a) What are the distributions of effort, which we will call design energy, put forth by the communities into the relevant technical, user experience, and method details of haptic application design?

RQ1(b) Have design energy distributions been changing under different circumstances?

RQ1(b i) Different on a community level?

RQ1(b ii) Different on different years?

RQ1(b iii) Different on different sized venues?

Focal Point 2 - Purpose of Haptics in User Experiences

RQ2(a) Who are the typical users being targeted for haptic support?

RQ2(b) What are the design reasons for using haptics to support these users?

Focal Point 3 - Design Methods Used to Create Haptic Applications

RQ3 What are the typical techniques and considerations used by the communities in practicing the technical and user experience aspects of haptic application design?

Focal Point 4 - Understanding Community Perspectives on Haptic Application Design

RQ4(a) How does each community self-report their haptic application design activities, through the lens of their publications' keywords?

RQ4(b) How do practitioners representing the communities view haptic application design practices? Do they interpret each community's published technical, user experience, and method details similarly or differently?

1.2.2 Methodological Approach

Our chosen methodological approach was a scoping review. This type of literature review was chosen as it provided a structure to synthesize representative community literature on haptic application design practices. We will explain the full details of why a scoping review was the most appropriate form of literature review in Chapter 3 (Approach). We will explain the exact methodology of our scoping review in Chapter 4 (Methodology).

Generally, our scoping review involved:

- Selecting haptic application design papers from representative community venues (conferences/journals). We selected papers that provided a balanced set of technical, user experience, and design method details used in haptic application design.
- Analyzing papers in a comparative, iterative manner inspired by frameworks such as design thinking [4], and qualitative coding techniques such as open coding [5].

1.3 Contributions

1. **Methodology:** A demonstration of how a scoping literature review may be used to compare design practices between defined samples (e.g. community or period of time). This methodology could be used as a basis for other comparisons.
2. **Characterization:** A first analysis of applicable haptic application design practices of two notable haptic research communities (HCI and Haptics), with objective and descriptive data on areas of similarity and differences.
3. **Implications:** We present preliminary implications and suggestions of how haptic application designers could use each community's design knowledge for more effective haptic application design.

Chapter 2

Background: Communities That Do Haptic Design

An initial understanding of community haptic application design behavior, such as possible expertise areas and types of design advice given, can motivate the need to investigate whether community design practices are different/similar on a larger scale.

We will provide historical backgrounds and examples of design behavior that are potentially emblematic of each community's haptic application design behaviour. We will also discuss a few papers that has tackled the topic of haptic application design.

As mentioned in Chapter 1 (Introduction), the literature references in this section were not part of the final set of analyzed papers. These papers were chosen from an initial reading of literature informed by our inital exploration of conducting a cross-disciplinary literature review. We chose papers within the range of years/types of venues notable in overall size, and types of haptic design knowledge.

However, these papers were not part of the actual set of papers used for analysis due to the extensive time/energy required for full analysis. For example, we looked at papers from CHI (ACM Conference on Human Factors in Computing) and UIST (ACM Symposium on User Interface Software and Technology) 2016. From these types of venues, we read papers in which their titles, metadata keywords, and abstracts alluded towards providing design details in each area of haptic application design described in Chapter 1 (Introduction). The purpose of the reading these papers was to provide initial premises of how haptic application design practices may or may not be different among the communities.

2.1 Haptics Community Background

2.1.1 Origins of the Haptics Community

Many different research groups have contributed to haptic research areas such as perception modelling and technological engineering. One important group were Engineers developing technology to recreate physical sensations inside virtual reality environments. In 1992, ASME (The American Society of Mechanical Engineers) formed a teleoperators and virtual environments journal. This was one of the first notable academic venues for haptics related research [6]. In 2008, this North American meeting changed its name to IEEE Haptics Symposium [7].

Biomedical Engineers also contributed to the development of haptic technology that allowed for safe but realistic medical training. Venues such as the IEEE (Institute of Electrical and Electronics Engineers) Transactions on Biomedical Engineering is just one example of several venues utilizing haptic technology [8].

Engineering researchers were often focused on overcoming the mechanical challenges of recreating haptic sensations [9]. Engineering researchers soon realized the importance of understanding haptic perceptual processes to create salient haptic sensations. Thus, Engineering researchers began to collaborate with Psychophysicists in order to marry technological advances with important haptic perceptual knowledge.

This led to collaborative venues where the Engineers and Psychophysicists could share their research findings with each other. For example, a conference called Eurohaptics was first held in 2001 [10]. In 2005, the North American Haptics Symposium combined with Eurohaptics to form a new meeting called Worldhaptics, which has continued to run in alternate years on different continents [11]. While the European and North American and more recent Asian communities vary somewhat, each are consistent in the emphasis of engineering and psychophysical research rather than human computer interaction related research.

The Haptics community has shown examples of adopting ideas from other research groups. Thus, it would be interesting to see whether the community's haptic application design approach is comparable to that of a design-oriented community (HCI).

2.1.2 Examples of Application Design in the Haptics Community

In one of a few notable works describing haptic application design in a cross-disciplinary manner, MacLean et al. provided insights into designing with haptics by drawing upon interaction design and haptic perception knowledge such as user goals, and haptic roles within a multimodal interaction experience [12]. Several areas of applications were also described.

One area of applications have designed haptics to act as a form of active feedback where knowing persistent information was critical, such as presentation timing and posture correction [12]. This form of active feedback has also been found helpful in reducing errors in physically operated tasks such as surgical training and navigation. For example, Bae et al. developed a needle insertion system during biopsy operations where the haptic signals were used to assist needle steering [13]. Girbes et al. developed a haptic feedback system that sought to reduce pedestrian accidents at low bus driving speeds [14]. Wang and Kuchenbecker developed a haptic alert system that used a white cane that encoded distance information via vibrotactile signals. These signals warned users with visual impairments of upcoming low hanging objects [15].

Other application areas have been used to support immersion in augmented media experiences such as virtual object interaction, and multimodal movie viewing experiences [12]. Gabardi et al. developed a novel haptic thimble fingertip wearable device that utilized a movable vibration based actuator that could convey virtual object edges and surface textures [16]. Lee et al. described the development of algorithms that could map a video's camera motions and sound effects into appropriate motion chair movements and vibration effects respectively [17].

2.1.3 Hints of Haptic Application Design Practices

Some examples from the Haptics community suggest that haptic application design relevant knowledge may come in the form of different design tools informed by other creative mediums.

Inspired by music composition, Lee et al. created VibScoreEditor, which used the concept of vibrotactile clefs for the creation of vibrotactile effects [18]. Danieau et al. described haptic effects informed by cinematic camera movements to enhance multimodal film viewing experiences [19].

There have been some movements towards the creation of design tools focused on supporting design activities/concepts such as iteration and design spaces.

Similar to the idea of video or audio clips, Enriquez and MacLean proposed the notion of haptic icons, pre-programmed haptic effects that could be utilized in a modular fashion to support haptic effect editor programs [20]. Building off this modular concept, Schneider and MacLean developed *Macaron*, a web-based vibrotactile editor that allowed haptic designers to browse examples of vibrotactile effects, and to rapidly create new effects by sketching/refining/mixing properties from other effects [21].

In design space relevant research, Seifi et al. explored user expectations and preferences of different visual organization schemas for customizing affective vibration effects [22]. In a later study, Seifi and MacLean developed a visualization tool called VibViz that organized diverse vibration effects into various facets that could be filtered and explored according to affective and practical user considerations [23].

2.2 HCI Community Background

2.2.1 Rising Interest in Haptic Technology

To the best knowledge of the paper authors, one of which is an established researcher spanning both HCI and Haptics communities, the HCI community has only recently began designing with haptic technology. This established researcher, Karon MacLean, has over 30 years of haptic design related publications covering haptic applications, design tool support, conceptual design, affective computation, and technical contributions.

From interviewing this researcher (personal communication, Feb 15, 2019), it was roughly in 2012 when the HCI community began to show an interest in using haptic technology. This was based on the number of haptic technology involved papers appearing in the flagship HCI conference - CHI (ACM CHI Conference on Human Factors in Computing Systems). In particular, the novel interaction techniques area exhibited more haptic-related papers. This researcher also noted the prevalence of haptic technology in other HCI relevant venues such as UIST (ACM User Interface Software and Technology).

Thus, it would be interesting to investigate this observation in a detailed manner. This can help understand how a design-oriented research community designs with haptic technology compared to other communities.

2.2.2 Examples of Haptic Technology Usage in the HCI Community

In MacLean's overview of haptic design guidelines, another popular area of haptic applications has been affective computation. Haptic technology was described as helpful for enabling emotional qualities in various types of interactions [12].

Ueoka et al. investigated pressurized air vortexes as a potential way to affect user's emotional states for stress relief applications [24]. Allen et al. investigated how a breathing animal-like robot that reacted to user touch gestures could be used to mitigate stress and anxiety [25].

Similar to the Haptics community, some examples have also suggested that the HCI community is also interested in haptic information feedback applications. For example, Tam et al. developed a haptic wearable system that utilized signals to indicate timing informaton when giving oral presentations [26]. Pan et al. investigated how haptic feedback could be used as a form of bookmarking, to aid in quickly finding a point of interest inside audio materials [27].

2.2.3 Hints of Haptic Application Design Practices

The HCI community has provided some application design support tools to assist in application ideation. For example, tools have been developed to support haptic media capture and conversion, and taxonomies for exploring possible design directions.

Minamizawa et al. created a toolkit called TECHTILE, an easy to use haptic media creation toolkit. The toolkit focused on capturing auditory information that could then be transferred into vibrotactile equivalent effects using microphones, voice-coil actuators, and signal amplifiers [28]. Haptipedia is a visualization tool used to help design new haptic technology by exploring hardware metadata based on important device and interaction design attributes. These attributes have been derived from over 30 years of haptic literature [29]. Hamam et al. surveyed relevant virtual reality and QoS (Quality of Service) literature in order to create a taxonomy for evaluating the user experiences of haptic enabled virtual environments. The taxonomy considered technical, psychological, and physiological factors into a mathematical model for evaluating the overall quality of a haptic application [30].

The community has also provided some guidelines on using psychophysical ideas for a practical interaction context. Pusch and Lecuyer took theories of pseudo-haptic perceptual processes and provided contextualized tips for creating convincing pseudo-haptic illusions [31]. Loffler et al. used past colour research to test various physical colour metaphors and their ability to improve the physicality of tangible interactions [32].

2.3 Reviews and Compilations of Haptic Application Design

Interestingly, there are many haptic literature reviews focused on very specific design topics.

For example, many haptic literature reviews have focused on specific application areas such as driving support [33], medical training tasks such as needle insertion [34] and retinal surgery [35]. These reviews often focused on discovering the types of study designs (evaluation metric, tasks), and haptic models used.

While these literature review papers are useful, they lack the cross-disciplinary nature that is a focus of our work.

Some other examples of existing haptic application design literature suggests that application design knowledge is often represented as taxonomies and guidelines based on psychophysical foundations.

For example, Hale and Stanney developed an exhaustive set of psychophysically driven guidelines for informing haptic designers of the perceptual capabilities of various haptic receptors in the human body (eg. mechanoreceptor, kinesthetic receptor) and how certain haptic features such as skin motion, muscle tension, texture, edge detections can be best conveyed using haptic technological parameters (eg. force exertion, timing of stimuli, etc) [36]. Sjostrom provided practical design considerations for haptic applications supporting the visually impaired. These considerations involved providing clear navigation reference points, a means to search or get an overview of objects available to feel, spacing of virtual physical objects in an environment and more [37].

To our best knowledge, very few works have focused on the topic of cross-disciplinary haptic application design practices.

As mentioned before, MacLean et al. provided insights into designing with haptics by drawing upon interaction design and haptic perception knowledge such as user goals, and haptic roles within a multimodal interaction experience [12]. To the best of our knowledge, this work remains one of the most notable cross-disciplinary haptic application design works.

The work closest to our research topic and literature review approach is Song et al.'s data-driven content and semantic analysis literature review of popular haptic interaction categories across disciplines such as Computer Science, Engineering, and Psychophysics [38]. Unlike other types of literature reviews, Song et al. used a data-driven approach by scraping and aggregating over 6000 haptic interaction papers to create illustrative visualizations of popular cross-community haptic interaction design categories. We would certainly like to adopt elements of this approach, as several of Song et al's objectives aligns with our own research goal. Specifically, there was a common point of comparing haptic interaction areas across different disciplines.

If we had to offer a critique of Song et al's work, it is that unlike other types of literature reviews, the authors stopped short of full paper reading that may have provided deeper interpretations of their topic. It is standard for literature reviews to employ multiple readers, and paper inclusion criteria checks to ensure paper appropriateness for a given research topic [39].

Additionally, we believe our research is different from Song et al.'s in that we are not just discovering the popular categories of haptic interaction. What we also care to report are the exact techniques, and design rationales that addresses both the technical and user experience aspects of a haptic application.

Chapter 3

Approach

This chapter will provide clarity on the formulation of our focal points and their associated research questions. We will describe why a scoping review was chosen as the most appropriate type of literature review. We will describe decisions regarding the scope of our data analysis.

3.1 Focal Points and Research Questions

As mentioned in Chapter 1 (Introduction), the cross-disciplinary nature of our research in comparing two different types of research communities presented a challenge. In particular, it was difficult to formulate research questions that could meaningfully be applicable for both communities. In order to address this challenge, we generated focal points to help create more specific answerable research questions impactful for both communities and that could scale in analysis time/energy based on our small author team size.

In order to help generate focal points, we conducted an informal preliminary analysis using some haptic application design papers. In our case, focal points were cross-community concepts related to our research goal of discovering different/similar design practices across the HCI and Haptics communities. Our analysis involved reading several papers that were thought to allude towards haptic application design application details as based on their titles, meta-data keywords, and abstract details. Please note that this analysis process was a precursor to our formal paper search and analysis process that will be described in Chapter 4 (Methodology).

The papers used to generate focal points were based on personal knowledge and papers from well-known haptic research journals/conferences, such as from CHI 2016 (ACM CHI Conference on Human Factors in Computing Systems) and ToH 2016 (Transactions on Haptics). These papers were not part of the final set of papers used for analysis. Please refer to the Appendix for the example papers used in our focal point generation process.

Another important constraint of our research was to find a manageable number of papers that could be deeply analyzed for understanding community haptic application design practices. In order to determine the exact venues/years to use in our study, we estimated the number of papers we thought to be representative of haptic application design details based upon a keyword metadata analysis of different possible venues. This keyword analysis will be described in Stage 1 of Chapter 4 (Methodology). We used these keywords and the resulting number of associated papers to help decide which venues and years could provide potentially impactful papers for analysis. Additional clarity on our study's scope can be found in Chapter 4 (Methodology).

We brainstormed and iterated upon several focal points of concepts involved in the technical, user experience and design methods of haptic applications. The initial ideas for possible focal points were inspired from our readings of notable community venue papers hinting about haptic application design practices in regards to our areas of interest (technical, user experience and design methods of haptic applications). After generating many focal points, we converged them into focal points that yielded research questions with interesting implications on cross-community design practices. Focal points were also chosen if clear data sources (eg. paper metadata keywords) could be used. Our chosen focal points provided a mix of quantitative and qualitative data. These could be used to both describe and summarize the overall prevalence of certain design behaviours.

It is important to note that this style of research, a cross-disciplinary literature review, was new for the author team. Thus, there was much refinement and iteration of our focal points and research questions throughout the study.

Please refer to Figure 3.1, to see a visualization of our focal point formulation process. Please refer to Figure 3.2 for seeing the rationale of why we chose our final focal points and the types of data we thought must be gathered from our literature review.

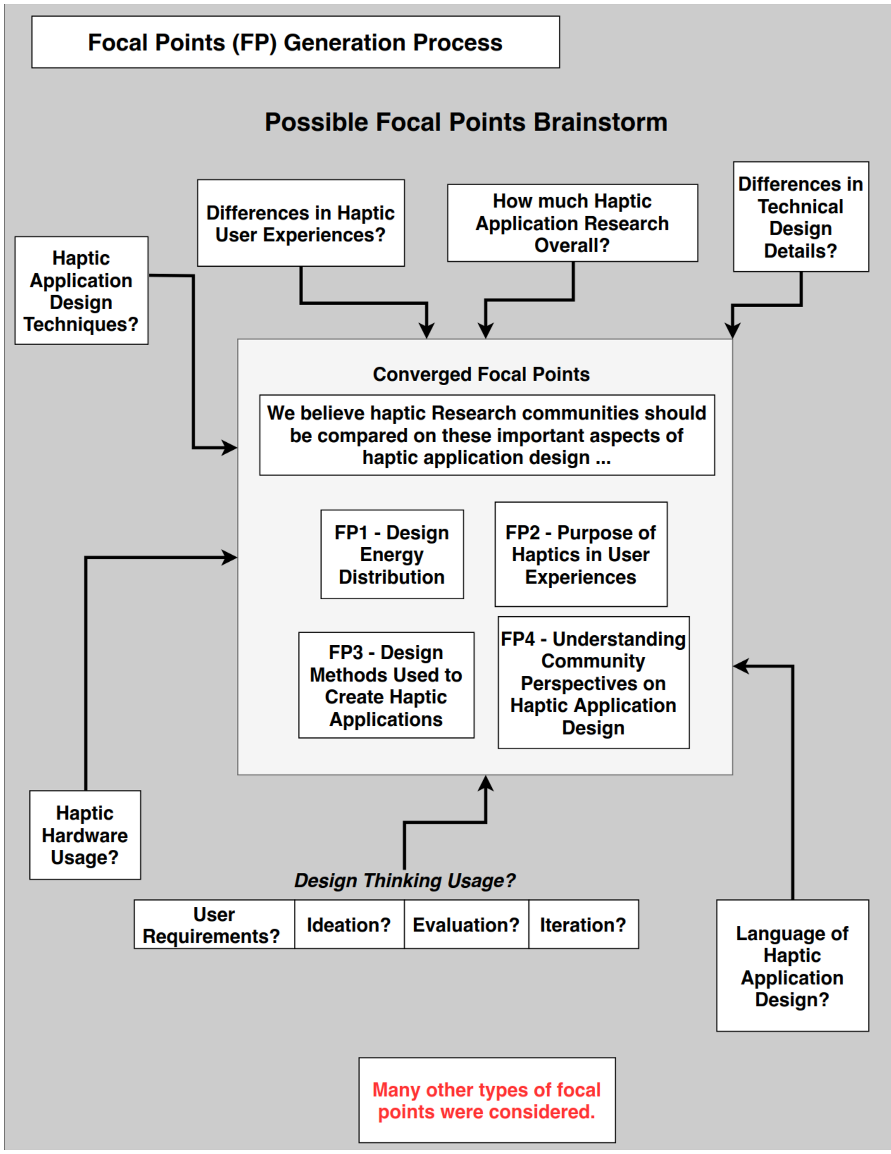

Figure 3.1: An illustration of our focal point formulation process. Outer boxes represent initial possible focal points. Inner boxes represent converged focal points based on outer boxes.

Figure 3.2 shows our chosen focal points based on their implications on cross-community design practices and whether a clean source of insight could be used to answer related research questions.

Focal Points	1. Design Energy Distribution	2. Purpose of Haptics in User Experiences	3. Design Methods Used to Create Haptic Applications	4. How Different is Haptic Application Design Between Communities?
Research Questions	a. What are the distributions of effort (design energy) put forth by the communities into the relevant technical, user experience, and method details of haptic application design? b. Have design energy distributions been changing under different circumstances? i. Different on a community level? ii. Different on different years? iii. Different on different sized	a.Who are the typical users being targeted for haptic support? b. What are the design reasons for using haptics to support these users?	What are the typical techniques and considerations used by the communities in practicing the technical and user experience aspects of a haptic application design?	a. How does each community self-report their haptic application design activities through the lens of their publications' keywords? b. How do practitioners from the communities view haptic application design practices? Do they interpret each community's published technical, user experience, and method details similarly or differently?
Implications	This can help understand the exact areas of haptic application design a community feels obligated to detail.	This can help characterize the exact types of user application areas a community is best at supporting. This can allow for other communities to draw upon another community's expert knowledge	This can help specify the exact types of design techniques that are being used by the communities. These techniques can be used as a reference for solving particular haptic application design issues (cross-fertilization)	This can help characterize the degree of similarity/differences in the ways communities talk and view each other's design work.
Source of Insight	Haptic Expert Ratings of Haptic Application Design Level of Details On Different Sample Groups (eg. Years)	Qualitative Coding of Relevant Haptic Application Design Papers	Qualitative Coding of Relevant Haptic Application Design Papers	# of Shared Keywords Haptic Expert Rating Distributions

Figure 3.2: Our final focal points and associated research questions based on cohesiveness with focal points, implications, and a clear means for insight.

3.1.1 Focal Point 1 (Design Energy Distribution)

In Chapter 2 (Background), there were suggestions that community backgrounds may have directed the types of haptic application design activities being conducted. The Haptics community seemed to be focused on engineering problems, while the HCI community were using haptic technology in a human centered design context.

Whether these behaviours were occurring on a larger scale required further verification. Thus, Focal Point 1 was chosen to capture quantifiable measurements of community investments into the technical or experience design areas of haptic application design.

The results of this focal point could implicate the exact design areas that each community felt obligated to detail. Data for this focal point could come be quantified scores indicating the degree of detail provided on haptic application design areas.

In order to maintain objectivity, these scores can be provided by community representative haptic experts. These scores could be collated in different ways to see if design energies were changing at all in different years, or from different sized academic venues.

3.1.2 Focal Point 2 (Purpose of Haptics in User Experiences)

We were curious about the types of user applications that were supported by the communities. This would be useful for communities designing a user application addressed by another community. The new community could study the design practices of a veteran community in order to make effective haptic application design decisions.

Complementary to user experiences, we thought it was important to understand the purported design reasons of using haptic technology to support user experiences. For example, MacLean et al. described that haptics could be used to achieve interaction goals such as information notification or physical constraint/guidance [12]. It would be interesting to compare the community's perspectives on the "best role" that haptic technology should take in an interaction. This could be useful for communities wishing to achieve a specific interaction goal, in which the community with the most expertise could be consulted.

Given these curiosities, Focal Point 2 was chosen to characterize the space of each community's supported user experience areas. We anticipated that this focal point would require a form of qualitative analysis that would involve reading and synthesizing the most notable user experience details into labels common among the communities.

3.1.3 Focal Point 3 (Design Methods Used to Create Haptic Applications)

We felt it was important to involve focal points that detailed the specific types of design methods used in the technical and experience design of haptic applications. For example, it would be useful to know about the haptic hardware used to implement applications. Thus, Focal Point 3 was chosen to catalogue the actual methods used in haptic application design.

This type of information would be useful for cross-fertilization, where communities could adopt specific design methods to solve certain design problems. Like Focal Point 2, we anticipated that qualitative analysis would be used to synthesize the notable types of design methods into labels that were common among the communities.

3.1.4 Focal Point 4 (Understanding Community Perspectives on Haptic Application Design)

It was mentioned in Chapter 2 (Background) that not all research within the HCI and Haptics communities would necessarily describe haptic application design.

For example, the HCI community focuses on interaction design involving a wide range of technologies such as VR/AR, smartphones, and more [40]. The Haptics community may focus on other types of haptic technology topics such as overcoming mechanical challenges [9] or investigating perceptual processes involved in haptic sensations [36].

Thus, given the diverse research topics within each community, it was possible that the language used to describe haptic application design would be different for each community. Similar to Song et al's metadata characterizations of haptic interaction concepts, we argue it is important to understand community words and how they can be used to characterize their respective perspectives on what concepts go into haptic application design [38]. Furthermore, the words can be used to indicate a degree of agreement, which we will define as a calculated value of the proportion of shared keywords between communities.

Focal Point 4 was chosen to capture whether the communities were similar in their words describing their perspectives on haptic application design. We also believed this focal point could be addressed by comparing different community experts and their respective views on the similarities/differences regarding haptic application design. This can be done by comparing Focal Point 1's expert quantifications of the technical, experience design, and design method details of each community's haptic application design papers.

3.2 Choosing Methodology

3.2.1 Why a Literature Review?

Our research goal was to discover the different/similar community design practices used to create haptic applications. This was to assess the potential for cross-fertilization, or knowledge sharing of design practices between the HCI and Haptics communities.

This large-scale research goal necessitated a methodology that could find, analyze, and synthesize large sources of information.

Literature reviews appeared to be the most appropriate methodology, as they examined literature to synthesize general patterns of a field, or to identify gaps in knowledge that could serve as the basis for future research [41].

However, many literature review options existed, each with different methodological constraints and research purposes. Thus, it was important to understand the differences among literature reviews in order to choose the most appropriate review.

3.2.2 Literature Review Overview

In general, literature reviews utilize representative papers to help answer large-scale research questions in different ways.

One class of literature review involves the summarization of large literature bodies to understand the current state or issues of specific research topics.

Traditional/Critical reviews summarize literature to critique theories using commonly reported methods/results [42]. **Conceptual reviews** summarize literature to help understand the issues of a specific research topic [42].

Another class of literature review rigorously screens literature to find informative research for high stakes situations.

Systematic reviews help make important decisions in risky domains such as government policy and medical treatment [43]. These reviews aim to collect strong evidence in an objective, reproducible manner in order to make an optimal decision. **Scoping reviews** can help characterize the existing nature of a research topic that can highlight knowledge gaps addressable by future research initiatives [43].

In our study, scoping reviews were decided to be the most appropriate literature review.

3.2.3 Why a Scoping Review?

For our research, we believe that scoping reviews were the best choice given the methodological constraints/limitations posed by other types of literature reviews.

Both traditional/critical and conceptual reviews do not necessitate a strict methodology for justifying paper selections. Thus, there is a risk of paper selection bias that may undermine our research goal of discovering large-scale community design insights [42].

Systematic reviews necessitate strict, standardized criteria to find informative papers for objective decision making. Unlike the medical domain, we are not aware of any standardized means to conduct haptic application design literature reviews in a cross-community comparative manner. Systematic reviews requirement of standardized procedures, such as the PRISMA system used by the medical domain, precluded these reviews as a literature review option [44].

Different researchers have used scoping reviews to perform cross-disciplinary analysis of different disciplinary methodologies.

For example, Coemans and Hannes used a scoping review to understand how arts-based methodology of community inquiry on vulnerable populations was practiced across the social science and education research communities. Notably, Coemans and Hannes defined a clear search and analysis strategy to investigate different rationales for using arts-based methods, the genres of methods used, and the benefits/limitations of arts-based methods [39]. Kitson et al. used a scoping review to understand how immersive interactive technologies, such as virtual reality and augmented reality, were designed to support positive physiological or emotional change in users. This review addressed how different research disciplines such as HCI and Psychology designed immersive technologies [45].

These examples demonstrate that scoping reviews are powerful tools that can objectively search and analyze relevant literature, even literature across different research disciplines. This cemented our confidence in using scoping reviews as our main approach in discovering the similarities/differences of community haptic application design practices.

3.3 Scoping Review Methodological Requirements

Section 3.2 demonstrated why scoping reviews were the best choice in understanding potential differences/similarities in community haptic application design practices. However, the exact methodological steps were not specified.

Fortunately, Arksey and O'Malley outlined a helpful framework for conducting scoping reviews, intended to help find and summarize relevant information from appropriate research papers [46]. The framework described stages such as:

1. Identifying the research question
2. Identifying relevant studies
3. Study selection
4. Charting the data
5. Collating, summarizing, and reporting the results

In terms of identifying research questions, Section 3.1 described how we formulated research questions through a preliminary analysis of haptic application design papers. We also described the justification of our chosen focal points and the types of data/implications that could address community haptic application design practices.

Chapter 4 (Methodology) will address the remainder of Arksey and O'Malley's framework stages. We will describe the details involved in identifying and selecting relevant studies, as well as the processes involved in analyzing (charting, collating and summarizing) the results.

It is also worth noting that Arksey and O'Malley described this framework as being more iterative, despite the linear order of stages presented. As we'll describe in Chapter 4 (Methodology) and Chapter 5 (Results), we can attest to the iteration needed to find fair comparison points of HCI and Haptics community design practices.

3.4 Scope of Data Analysis

Chapter 4 (Methodology) will describe the exact steps involved in finding and analyzing haptic application papers. We wanted to clarify how resulting data would be handled in the analysis described in Chapter 4 (Methodology).

3.4.1 Quantitative Data Clarity

Focal Point 1 and Focal Point 4 were expected to yield quantitative data. This data was expected to be the distribution of score categories (each category representing a degree of design detail) provided by experts on different areas of haptic application design.

Readers may be surprised to see that this data will not be analyzed using inferential statistical techniques such as ANOVA. Inferential statistics was not used, due to the small author team size limiting the number of papers for effective inferential statistics. Inferential statistics was also not suitable due to our study's focus on characterizing rather than confirming community differences in design practices. Future work could potentially use inferential statistics to confirm the relevance of our discovered design practices.

3.4.2 Qualitative Data Clarity

Focal Point 2 and Focal Point 3 were expected to yield qualitative data. As Chapter 4 (Methodology) will describe, we will use qualitative analysis techniques inspired by open coding that will characterize general patterns of community design behavior into labeled codes [5]. These codes are useful in succinctly describing general patterns of haptic application design behavior. Arksey and O'Malley also suggested that mechanisms like codes could be used to summarize and report the distribution of analyzed behavior among the papers used in a scoping review [46]. This would be useful for our study, due to the large-scale nature of our research goal benefiting from numerical styles of data reporting.

Chapter 4

Methodology

This chapter will describe the detailed steps of our scoping review. We will also report the exact number of papers considered at each stage of our scoping review, in order to illustrate the size of research considered by our work.

Specifically, we will describe the methodological steps inspired by Arksey and O'Malley's scoping review framework. Our stages involved determining the right scope of academic venues/years appropriate for our study, identifying possible haptic application design papers, screening papers for study appropriateness, and analyzing screened papers to answer our research questions.

When necessary, we will present figures that will visually clarify the methodological steps taken.

4.1 Summary of our Scoping Review

Figure 4.1 visually summarizes our scoping review's stages and their respective approaches. As Arksey and O'Malley described in their framework, it is not uncommon to iterate between or on certain stages of a scoping review. Interestingly, we took much time to determine the right academic venues that should be the source of potential haptic application design papers [46]. This is indicated by the reverse up and down arrows in Figure 4.1 between Stages 1 and 2. Additionally, we performed successive refinement of our focal points, eventually coalescing into the final focal points reported in earlier sections.

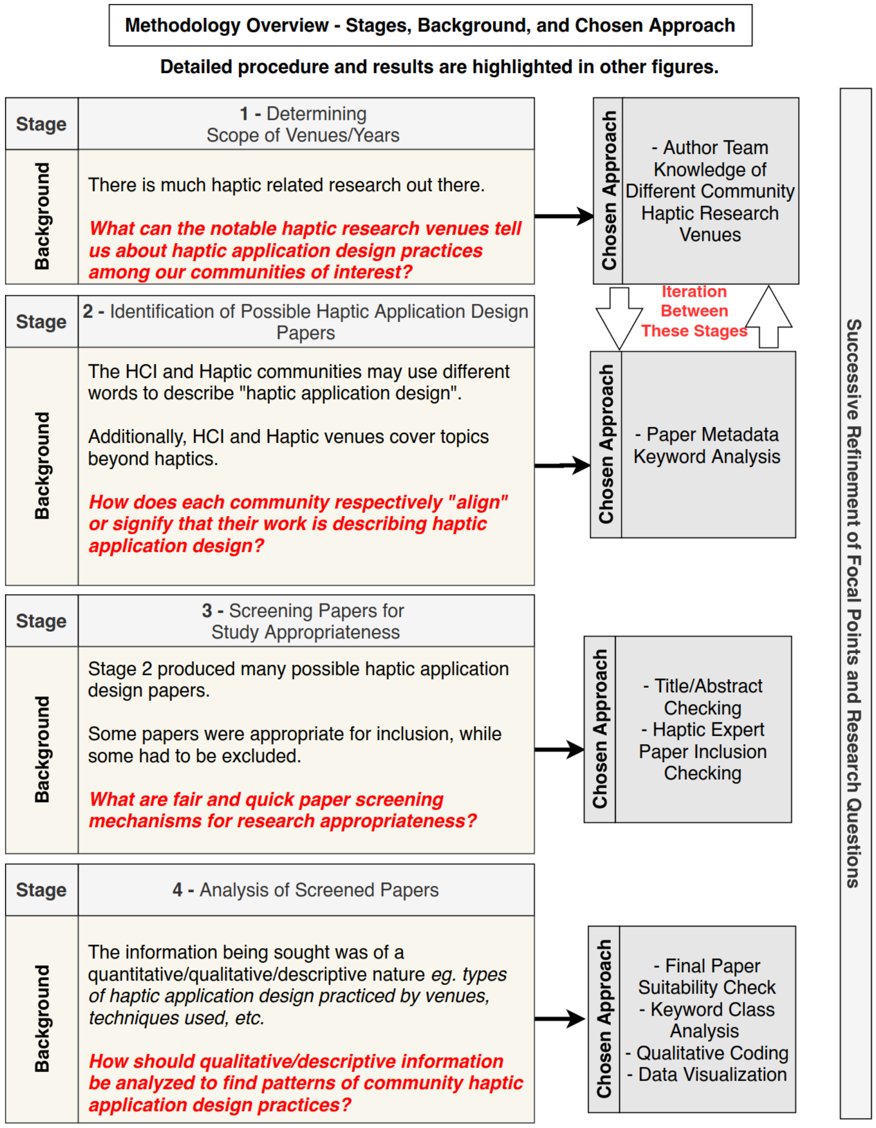

Figure 4.1: A high level overview of our scoping review stages.

Please refer to each stage's respective section after this summary for finer details.

4.2 Research Space Size

Medical scoping reviews tend to report numbers on the overall research space (paper numbers) being considered and curated by a scoping review methodology [47].

Due to the cross-disciplinary nature of our study, we also wanted to report the large scale of research that was being addressed, in order to highlight the challenges of determining the degree of haptic application design research occurring in the HCI and Haptics communities.

Figure 4.2 summarizes how our methodology affected the research space at each stage of our scoping review.

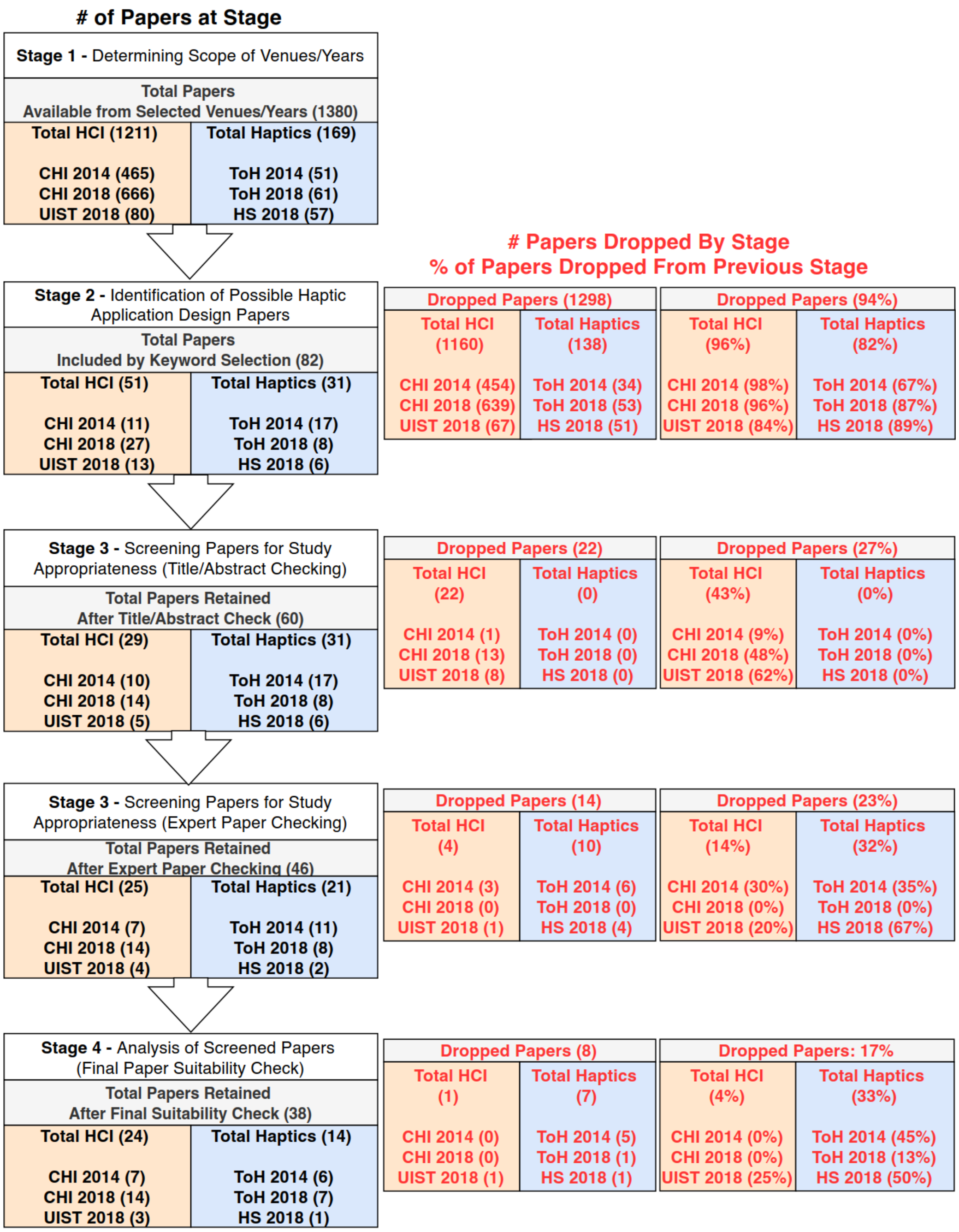

Figure 4.2: An overview of how our research space changed at each stage of our scoping review. CHI, UIST, ToH and HS are acronyms for HCI and Haptics publication venues which will be elaborated in Section 4.3.

4.3 Stage 1. Determining Scope of Venues/Years

Common to most researchers, using existing knowledge of conferences, and other academic organizations can be a viable method for determining sources of relevant studies [46]. This was the approach used in determining the appropriate venues (conferences, journals) that we believed to be representative of haptic application design practices based on our preliminary focal point generation process described in Chapter 3 (Approach). Please note that these venue acronyms will be used going forward.

We decided that the HCI community would be best represented by:

- ACM Conference on Human Factors in Computing (**CHI**)
- ACM Symposium on User Interface Software and Technology (**UIST**)

We decided that the Haptics community would be best represented by:

- IEEE Haptics Symposium (**HS**)
- IEEE Transactions on Haptics (**ToH**)

To our best knowledge, this study is one of the first studies investigating research from different types of communities involved in haptic application design. The main author team faced limitations in the amount of data that could reasonably be searched and analyzed as indicated by Figure 4.2. Based on that figure, our choice of four venues yielded 1380 papers without any inclusion checking. This was a large number of papers that could not be easily analyzed. Thus, scope reduction steps that filtered towards papers with relevant details was a necessity.

In terms of years, we focused on 2014 and 2018 for detecting any possible design practice changes. These two years were chosen as it provided a means to anchor recent design practices (2018) with an interval of time large enough to show potential changes in any practices (2014).

Involving more years or larger gaps of time could show a larger change in design practices. Due to the small author team size, we required a gap of time that could still show potential change yet remained feasible for analysis.

Hence, only 2014 and 2018 were chosen as they represented important start and end points of a time period thought to represent important developments in haptic application design. These anchor point years was also substantiated by our haptic expert author.

Our choice of focusing upon 2014 and 2018 was further cemented by our estimation of the number of haptic application design papers of different venue years. These estimations were based on a keyword analysis, that will be described in Stage 2 Step B of our methodology. Paper metadata keywords were used to help find potential haptic application design papers, but these papers were not read, unlike in Stage 2 Step B of our methodology.

Figure 4.3 shows the estimations of haptic application papers during the years 2014, 2016, and 2018, compared with the original total number of papers published in a community venue.

Venue/Year	Total # Papers	# Potential Haptic Application Design Papers
CHI 2014	465	36
CHI 2016	543	50
CHI 2018	666	46
UIST 2014	74	7
UIST 2016	79	17
UIST 2018	80	20
HS 2014	106	49
HS 2016	52	20
HS 2018	57	11
ToH 2014	51	26
ToH 2016	56	25
ToH 2018	61	24

Figure 4.3: Stage 1. Our estimation of some notable venue year's haptic application design papers. A venue was considered for inclusion at this stage based on keywords only. Papers were not read at this point.

For CHI, we decided that 2014 and 2018 would be sufficient for our study, due to the similar estimations of haptic application papers in each year (average of 44 papers). Based on these similar estimations, we decided that dropping CHI 2016 would assist in keeping a manageable sample set for analysis and not risk much in losing helpful papers.

For UIST, we decided that 2018 would be sufficient for our study, due to Figure 4.3 indicating that the years 2014 contributed only 7 potential haptic application design papers.

Additionally, we wished to maintain parity with our time span anchors of 2014 and 2018, thus only 2018 was decided to be kept. Fig 4.3 also indicated that 2018 had as many potential haptic application design papers as 2016 (20 versus 17 respectively). Given these reasons, we felt that we wouldn't lose much by dropping UIST 2016 from our scope of years.

We took some time to carefully consider the venue year choices for our Haptics venues. While one may suspect that the HS conference should also use the years 2014 and 2018 to maintain parity with our HCI CHI conference, we did not do so based on our estimation numbers. For HS, Figure 4.3 indicated that 2014 had 49 potential haptic application design papers, and that 2018 had 11 potential papers. This disparity in numbers, unlike CHI, indicated that comparing these two HS years maybe unfair. By comparison, ToH seemed to provide more stable estimations, where Figure 4.3 showed that 2014 and 2018 could serve an average of 25 papers consistently. Thus, given the similar estimations of anchors years (2014 and 2018), it was decided that ToH should involve two years for analysis, while HS should keep 2018 in order to maintain parity with our UIST 2018 choice.

4.4 Stage 2. Identification of Possible Haptic Application Design Papers

Scoping reviews often use a fixed set of search terms as an inclusion criteria (ie. applying the same terms to all databases searched) [45].

However, in Focal Point 4 we observed the likelihood that each of our communities used different keywords for activities related to haptic application design. We suspected that our communities may differ from those more conventionally scanned in scoping reviews.

Thus, we needed another way to identify papers using keywords that would be applicable to both communities. Figure 4.4 illustrates the actions involved in the identification of possible haptic application design papers.

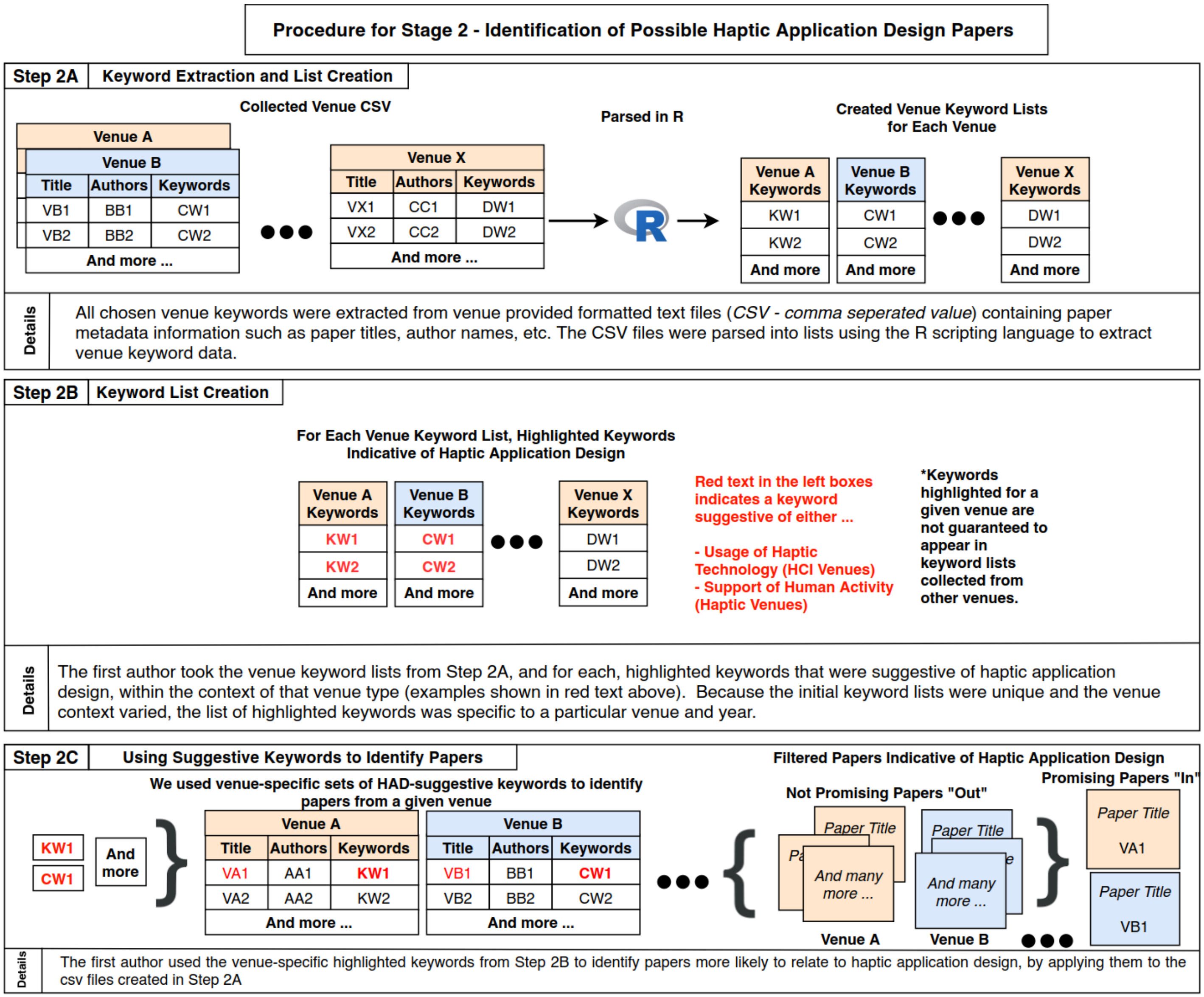

Figure 4.4: Stage 2. An overview of identifying possible haptic application design papers. Real keyword data is not given. Please refer to the results for keyword data examples.

4.4.1 Step 2A. Keyword Extraction and List Creation

In order to discover useful haptic application keywords applicable to the communities, we extracted metadata keywords from our chosen venue/year papers.

In order to extract keywords, we used a critical Export CSV feature available in the ACM Digital Library and IEEE Xplore databases that held our venue papers. This feature exported a parsable comma separated value (CSV) spreadsheet file that contained important metadata information such as paper titles, authors, and keywords. Some venues such as EuroHaptics had to be disqualified due to archival reasons that precluded metadata retrieval.

Once the CSV files were obtained, we created R scripts to parse each venue's keywords into lists that could be reviewed by the main author team.

4.4.2 Step 2B. Keyword List Creation

We reviewed the venue keyword lists and chose keywords suggestive of haptic application design related concepts based on the backgrounds of the HCI and Haptics communities. To clarify, for each venue/year, keywords were chosen independently and specifically for that particular venue/year. We used these venue/year specific keywords in our next step of identifying possible haptic application design papers.

Figure 4.5 and Fig 4.6 shows the keywords chosen for the HCI and Haptics communities respectively.

HCI Venue Keyword List

CHI 2014 Keywords	Count
actuated display	1
actuated interfaces	1
expressive touch	1
force	3
force-feedback	1
haptic devices	1
haptic feedback	3
haptic interface	1
haptics	1
hybrid touch and mouse interaction	1
indirect touch	1
midair	1
mid-air	1
mid-air interaction	1
mid-air interactions	1
mid-air text-entry	1
physical computing	1
physical controls	1
pressure	2
pressure input	1
shape changing object	1
shape displays	1
shape-change	1
shape-changing	1
shape-changing interface	1
shape-changing interfaces	1
skin conductance	1
social touch	1
surface haptics	1
tactile	1
tactile interface	1
touch	5
touch input	4
touch interaction	1
vacuumtouch	1
vibro-tactile	1

CHI 2018 Keywords	Count
actuated interfaces	1
actuated tangibles	1
asymmetric vibration	1
electrical muscle stimulation	2
electronic skin	1
electrostatic force	1
facial electrical stimulation	1
force	2
force feedback	2
haptic	1
haptic display	1
haptic feedback	3
haptic force feedback	1
haptic illusion	2
haptic interfaces	1
haptic language	1
haptic links	1
haptic retargeting	1
haptics	11
human actuation	1
indirect touch	1
kinesthetic feedback	1
mid-air haptics	1
multimodal tactile display	1
muscle interfaces	1
paper actuator	1
physical interfaces	1
pneumatic actuation	1
pressure	1
shape changing	1
shape changing.	1
shape displays	2
shape memory polymer	2
shape-changing	1
shape-changing interfaces	4
shape-changing user interfaces	1
skin conductance	1
tactile	1
tactile display	1
tactile drawing	1
tactile feedback	2
tactile graphics	1
touch	2
touch input	1
touch interaction	4
touch-based interaction	1
touching	1
ungrounded force feedback	1
vibration information	1
vibrotactile	3
vibrotactile display	1
watch-back tactile display	1
wearable haptics	1
wearable tactile display	1

UIST 2018 Keywords	Count
actuated device	1
actuating human body	1
electro-tactile	1
facial haptics	1
force-feedback	1
haptic feedback	1
haptic illusions	1
haptics	7
magneto-haptics	1
physical computing	1
physical interaction	1
shape changing interfaces	1
shape displays	1
skin	2
tactile display	2
touch input	3
touch interaction	1

Figure 4.5: Stage 2. HCI-venue (CHI 2014, CHI 2018, UIST 2018) keywords thought to evoke haptic application design. This is the original paper keyword data.

Haptics Venue Keyword List

ToH 2014 Keywords	Count
Automobile Driving	3
Balance training system	1
ball chasing game	1
bimanual dental operations	1
biofeedback-based exercises	1
children socialization	1
Clinical diagnosis	1
clinical rehabilitation training	1
dendritic spines reconstruction	1
design for wearability	1
design parameter	1
design parameters	1
driver attention reorientation	1
driver information systems	1
Driving assistance systems	1
driving skills	2
dual-user haptic teleoperation systems	1
Exercise Therapy	3
hand rehabilitation	1
haptic feedback strategies	1
haptic interaction	1
haptic tumor augmentation	1
haptically assisted connection procedure	1
Haptically assisted segmentation	1
human computer interaction	4
Human computer interaction	1
human computer interactions	1
human factors	5
Human factors	1
human-centered computing	1
implicit HCI-based bookmarking	1
implicit human-computer interaction	1
implicit interaction	1
interaction capability	1
interaction forces	1
interaction tree	1
Microscopy	1
minimally invasive surgical procedure	1
Minimally Invasive Surgical Procedures	1
mixed kinesthetic-vibratory navigation cues	1
mobility training	1
motion control	2
motor learning	1
motor recovery mechanism	1
motor rehabilitation	1
motor relearning procedure	1
moving tactile warning signal presentation	1
neurocognitive robot-assisted exercises	1
neurocognitive robot-assisted therapy	1
Neurological Rehabilitation	1
neurorehabilitation	1
palpation training system	1
patient monitoring	1
post-stroke arm rehabilitation	1
Postural Balance	1
postural control	1
postural control rehabilitation	1
postural state monitoring	1
Posture control	1
rehabilitation	5
Rehabilitation	1
rehabilitation exercises	1
road traffic control	1
steering assistance	1
Surgery, Computer-Assisted	1
tactile communication systems	1
tactile direction cues	1
teleoperated needle insertion	1
tuned rehabilitation therapy	1
upper limb training	1
upper-extremity rehabilitation	1
user interaction	1
user mental models	1
user-centered design	1
vehicle reverse parking skills	1
vibrotactile warning signals	1
visuo-haptic interaction mechanism	1

ToH 2018 Keywords	Count
adaptive control	1
biomechanics	2
contactless laser surgery	1
Contactless surgery	1
driving posture	1
Emotion recognition	1
force feedback	3
handwriting skill development improvement	1
haptic interaction	3
haptic interfaces	1
high-dimensional haptic interaction signals	1
human computer interaction	1
human factors	2
Human factors	3
interaction force	1
laparoscopic surgery	1
laparoscopic tumor localization	1
laser applications in medicine	1
laser microsurgery	2
manual palpation skills training	1
modeling human emotion	1
MR-guided interventions	1
musical performance	1
needle insertion	2
real-world scenarios	1
surgical simulators	1
surgical training simulators	1
tactile alphabet	1
tactile alphabets	1
tactile augmented reality	2
tactile communication	1
tactile cues	1
Tactile Fruit Sorting game	1
tactons	1
tumor localization	1
vibrotactile alarm system	1
virtual interactive information	1

HS 2018 Keywords	Count
blood pressure measurement	1
design recommendations	1
foot-based menus selection	1
human computer interaction	1
human-to-robot handovers	1
menu selection task	1
motor skill acquisition	1
movement therapies	1
musical applications	1
navigational feedback	1
online shopping	1
patient diagnosis	1
patient monitoring	1
patient rehabilitation	1
pianist-piano interaction	1
social touch	1
surgical training	1
wearable scenarios	1

Figure 4.6: Stage 2. Haptics-venue (ToH 2014, ToH 2018, HS 2018) keywords thought to evoke haptic application design. This is the original paper keyword data.

Our thought process for choosing certain types of HCI-venue keywords were as follows:

- We tended to choose keywords suggestive of haptic technology such as "tactile display".
- This was due to the background of the HCI community being focused on interaction support for human activities.
- Keywords related to human activities were not a priority, as it was likely the HCI community's papers would implicitly cover an aspect of human activity support.
- Examples of unused keywords from the HCI community included "command selection" or "health information". These were keywords that implicated a human activity, but did not directly imply the presence of haptic technology.

Our thought process for choosing certain types of Haptics-venue keywords were as follows:

- We tended to choose keywords suggestive of human activities such as "motor rehabilitation".
- This was due to the background of the Haptics community being focused on developing haptic technology.
- Keywords related to haptic technology were not a priority, as it was likely the Haptics community's papers would implicitly cover technology details.
- Examples of unused keywords from the Haptics community included "closed loop control" or "electrovibration". These were keywords that implicated knowledge relevant to haptic technology, but did not directly imply the support of human activities.

For this study, we decided to use venue/year specific keywords, as we did not fully understand the general types of keywords that could be possibly repeated/shared among the different community venues. Future work could investigate the nature of each community's keywords such that a standardized list of keywords can be created to identify haptic application design papers reliably.

4.4.3 Step 2C. Using Suggestive Keywords to Identify Papers

We used our chosen keywords to find their associated haptic application design papers. This resulted in a set of candidate papers that appeared promising in providing haptic application design details.

We consolidated any duplicated papers into a single paper for consideration, as it was occasionally found that different keywords resulted in the same paper being identified. Searching with the keywords and consolidating duplicates led to 82 candidate papers (1380 papers went into Stage 1 and Stage 1 dropped 1298 papers).

4.5 Stage 3. Screening Identified Papers for Research Appropriateness

Scoping reviews can require an inclusion criteria to screen out papers that does not meet a set of research objectives [39]. In order to conduct paper screening, two steps are commonly used – title/abstract checking and multiple author checking of papers [46] [39] [45].

Please refer to Figure 4.7 to see how these screening steps were applied.

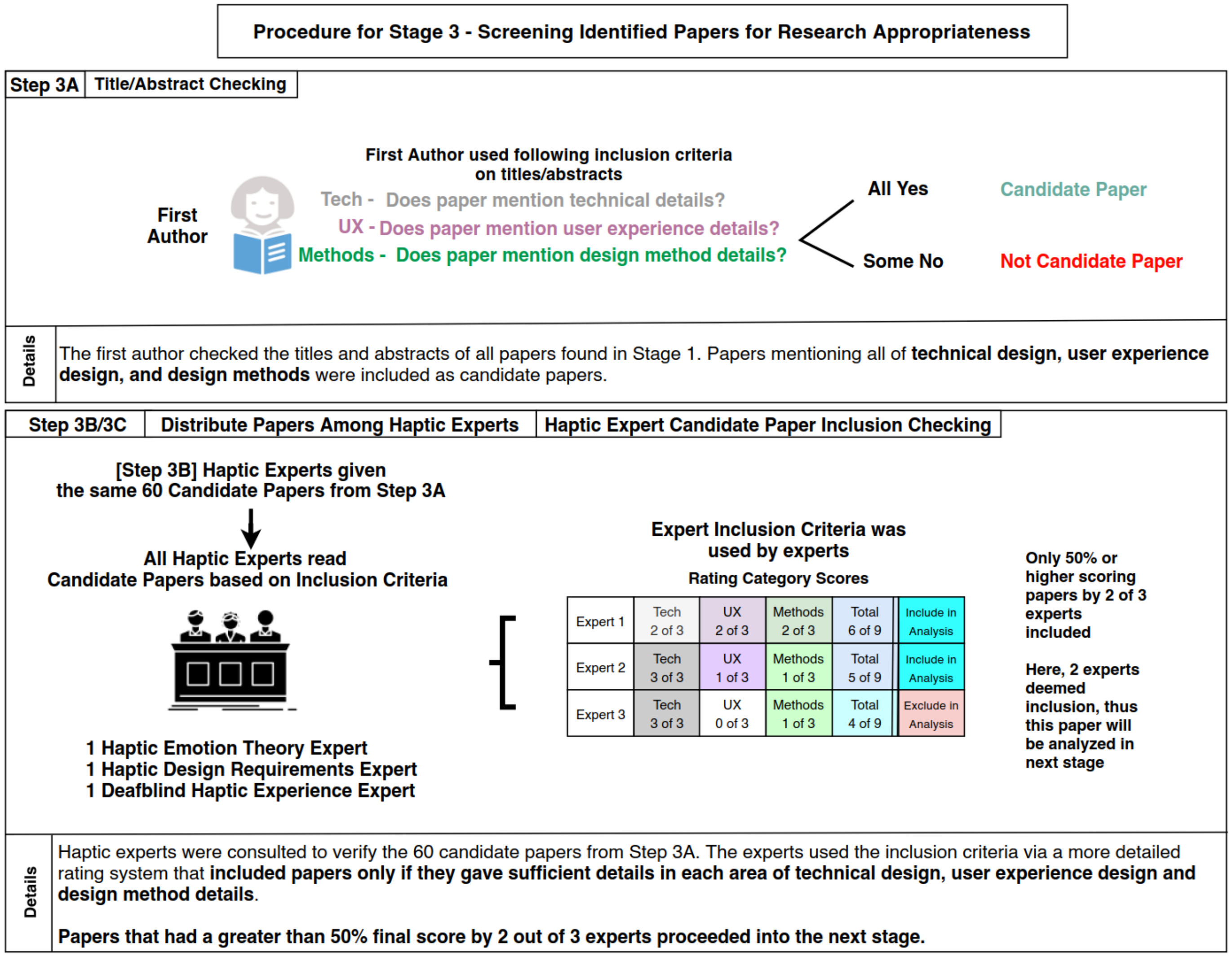

Figure 4.7: Stage 3. An overview of screening papers. Please refer to the results for haptic expert rating data.

4.5.1 Step 3A. Title/Abstract Checking

The first author read the titles, abstracts and if necessary, the body of Stage 2 candidate papers.

This was required in order to verify whether the candidate papers were indicative of our haptic application design areas of interest. For a paper to be considered appropriate, it must have described a balanced set of details pertaining to the technical design, experience design, and design method details of haptic applications. If any one of these areas were not addressed, the paper was screened out.

This step led to 60 candidate papers considered more promising of haptic application design details (82 papers went into this Stage 3 step and this Stage 3 step dropped 22 papers).

4.5.2 Step 3B. Distribute Papers Among Haptic Experts

As seen in Figure 4.7 in order to avoid paper selection bias, we took Step 3A's candidate paper set of 60 papers and consulted the help of three haptic experts. These experts reflected the different communities of interest in order to ensure a fair voting process of screening haptic application design papers.

We defined haptic experts to be published academics that were studying haptic research under a design perspective. These perspectives could be conceptual or technical in nature. Please refer to Figure 4.8 below to see our expert backgrounds.

As we will describe in the next section below, each expert was given the same 60 candidate papers from Step 3A to fully read and analyze for a screening task (Paper Inclusion Checking).

Identity	Expert 1	Expert 2	Expert 3
Community	HCI	HCI	Haptics
Topic	Haptic Emotion Theory	Haptic Designer Experience Requirements	Deafblind Haptic Experience
Experience Publication Years	5 Years	2 Years	2 Years
Published Venues	CHI DIS EuroHaptics ICMI ACII	HS	International Conference on Human Haptic Sensing and Touch Enabled Computer Applications AsiaHaptics
Hours on Task	4 Hours	4 Hours	4 Hours

Figure 4.8: Stage 3. Haptic expert background information.

4.5.3 Step 3C. Haptic Expert Candidate Paper Inclusion Checking

Based on our personal knowledge of academics that have studied haptic research from different community backgrounds, we personally contacted interested academics as described in Figure 4.8. Each academic expert was asked to perform a paper inclusion checking task. Each expert was tasked to independently read the 60 candidate papers from Step 3A. Each expert used the same 3-point scoring system that quantified the different levels of details given to each area of haptic application design (technical design, experience design, design methods). Each of these areas were given a score out of 3 points, and the subsequent tallied score would be used to indicate the overall level of haptic application design detail in a paper. The full details of this scoring system can be seen in Figure 4.9 below.

We ensured paid compensation for time committed to the task. We estimated that the task would take 3 to 4 hours to complete based on our piloting of the task. Each expert reported taking 4 hours to complete the task. Each expert was paid 40 Canadian dollars per hour.

Good Technical Haptics? **Specificity, recreation**	**Low (1/3)** Too vague, unsure how it all works	**Medium (2/3)** Some parts understand, some parts not	**High (3/3)** High specificity in technical details, enough for replicability.
Good Experience Design? **Motivated by human needs/problems/ capability**	**Low (1/3)** Activity, user type mentioned but not used to explore/validate haptic design choices (conceptual model) The haptic presence/need is not clear for the stated problem.	**Medium (2/3)** Interesting conceptual model inspired by human situations/problems but little to no validation yet. Their ideas for haptics are well thought out but is ultimately speculative.	**High (3/3)** Interesting conceptual model that is informed and validated by the people being designed for. The purpose of the haptics is convincing.
Good Design Method? **Rigour/Due Diligence**	**Low (1/3)** Did not validate haptic ideas with actual target activity group. Metrics chosen seem to validate the tech, not the human usage/reaction of the concept. For speculative works, the process/info leading to the ideas is not clear.	**Medium (2/3)** Did do reasonable evaluation activities appropriate for their design fidelity (prototype, speculative scenario), but the quality of analysis may seem lacking eg. inconclusive, results not presented in a convincing way	**High (3/3)** Clear sense of well done evaluations appropriate for the design, and answers presented in a way that clearly says if the design worked well or not.
Paper not actually about haptic experience Use when you find yourself "giving 0" for a given row above			

Figure 4.9: Stage 3. The scoring system criteria used by our experts.

Only papers that were given passing scores of over 50% by at least 2 out of 3 experts were considered appropriate for final analysis. This stage ended with 46 papers deemed suitable for further analysis (60 papers went into this Stage 3 step and this Stage 3 step dropped 14 papers).

The expert scores were also used to address Focal Point 1 and Focal Point 4. This was to characterize the design energies of different communities on different areas of haptic application design. This was also to understand how the different community experts were similar/different in their interpretations of haptic application design details. These will be discussed further in Chapter 5 (Results).

4.6 Stage 4. Analysis of Screened Papers

Our focal points and their research questions suggested several types of data to be analyzed, ranging from quantitative to qualitative in nature. Thus, it was important to consider the manner of presentation of the paper data as it was being analyzed. We detail how we presented our data below. Figure 4.10 describes our analysis process.

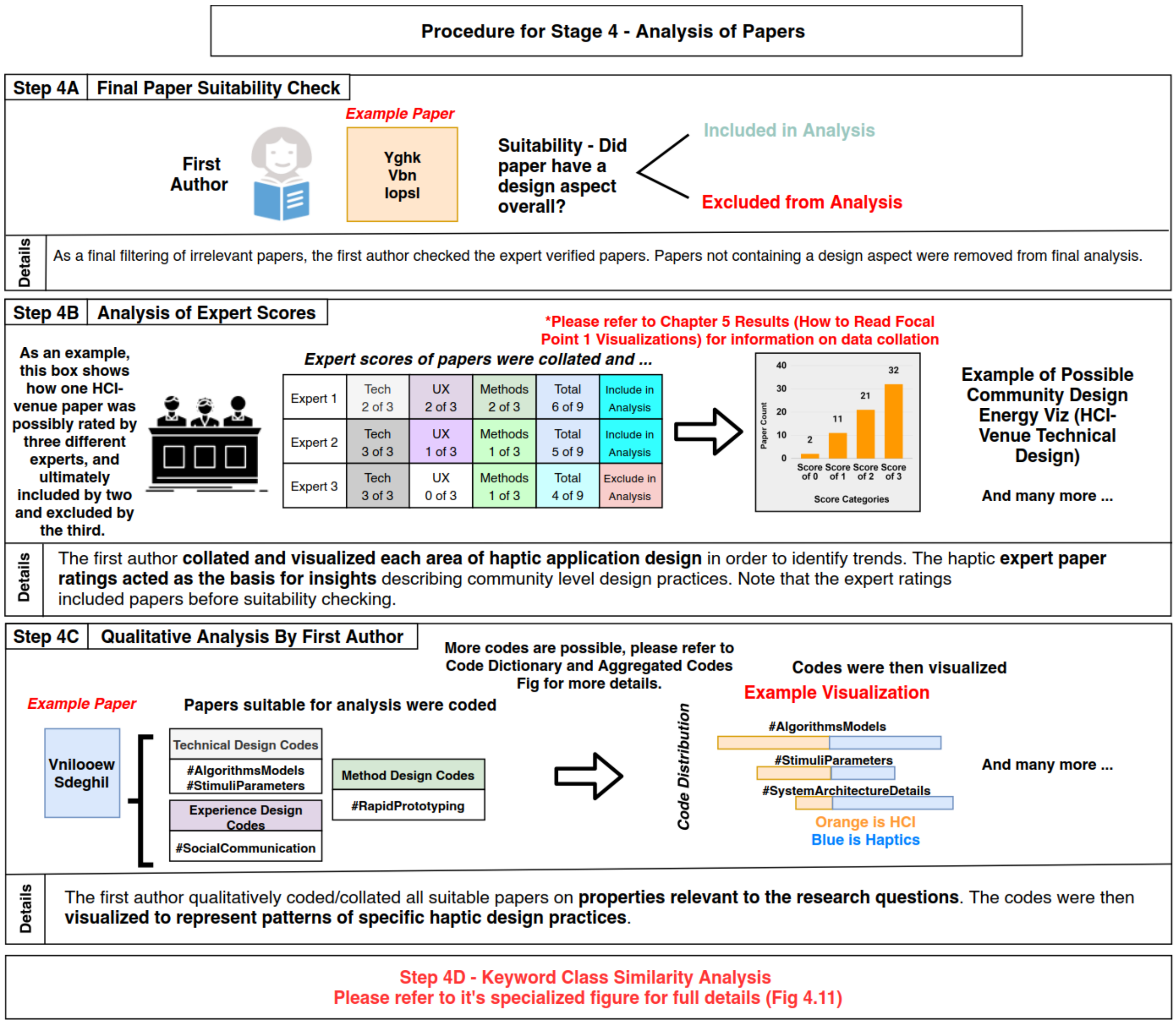

Figure 4.10: Stage 4. An overview of our analysis process up to Step 4C. Real paper names are not shown. The qualitative codes and visualizations are not based on real paper data. Please refer to the results for analysis data. Please refer to Fig 4.11 for Step 4D details.

4.6.1 Step 4A. Final Paper Suitability Check

The first author performed a final suitability check of the Stage 3 papers. This involved a full reading of each of the Stage 3 papers. It was found that some papers had to be discounted for further analysis, as some did not meet our inclusion criteria of providing a balanced set of haptic application design details.

For example, some papers were haptic perceptual studies that did not have direct implications on the experience design of haptic applications. Some papers were found to detail technical models/algorithms that were implicated but not informed by human activities. This reflects a limitation of our inclusion criteria provided to the haptic experts in Stage 3.

After the final suitability check, 38 papers were left for final analysis (46 papers went into Stage 4 and Stage 4 dropped 8 papers).

4.6.2 Step 4B. Analysis of Expert Scores

This analysis addressed Focal Points 1 and 4, where we sought to understand the distributions of design energies among the communities and whether community practitioners (our experts) viewed haptic application design differently from each other.

We considered the quantitative expert scores of Stage 2 to be a good basis for addressing these focal points. The expert scores indicated levels of design detail and could be visualized as distributions to identify the design areas of community focus and areas of expert agreement/disagreement.

In order to address our focal points, the first author collated and visualized the distributions of expert scores in different ways. To address Focal Point 1, the first author collated all the expert scores into a collective distribution to highlight the consensus of how community design energies were being distributed. To address Focal Point 4, the first author created different distributions of each expert's scoring behavior on different haptic application design areas.

Please refer to Chapter 5 (Results) to see how we visualized the expert scores.

4.6.3 Step 4C. Qualitative Analysis By First Author

This analysis addressed Focal Points 2 and 3, where we wished to specify the design methods and typical user experience areas/reasons of designing with haptic technology.

These focal points required qualitative information, thus we employed a qualitative coding approach inspired by opening coding [5]. This involved deeply reading and re-reading the 38 papers deemed suitable for final analysis in a comparative manner.

This goal of this process was to arrive at a set of codes that were simple words/phrases that would be reflective of a haptic application design behavior. For example, codes could describe the types of hardware being used among the communities. The creation of these codes involved much iteration and clustering of other smaller codes into more representative larger categories. This also involved looking back towards our focal points and research questions, and iterating upon them in order to find cohesive categories of focal points that best represented our code data in light of interesting implications for our communities. Please refer to Chapter 5 (Results) to see the resulting codes.

Once the codes were stabilized, we collated the codes to visualize distributions of community user experience areas, the design methods used in the technical design, experience design, design methods involved in haptic applications, and the purported design reasons to design with haptic technology.

4.6.4 Step 4D. Keyword Class Similarity Analysis

This analysis addressed another important aspect of Focal Point 4, in which we sought to understand how the communities described haptic application design based on the keywords being used.

Due to the nature of keywords being different from each community, we opted to consider the class of keyword rather than the keyword itself in order to allow for similarity comparisons. To be clear, keyword classes were independently and specifically made for each venue/year in our study. The keyword classes from each venue/year were then compared to see if any classes were repeated among certain pairings of venues/years. These mechanisms were based on a human judgement process, and may have been prone to imperfections.

The mechanisms we used to derive keyword classes were:

- Typically from long keyword phrases, we selected root word as the keyword class which was most relevant to our purpose.
- If different parts of a keyword phrase seemed indicative of a haptic application design, then each word of the phrase became a keyword class.
- If the entirety of a keyword phrase signaled a unique perspective on haptic application design, then the whole phrase was used as a class.
- Keyword classes were based on our interpretations of words that implied haptic application design from the perspective of each community.

We give examples of how these mechanisms played out in the different venue groups.

For HCI venues:

- Keyword classes tended to be haptic technology-related, given that the community has been known to perform interaction design using non-haptic technologies.
- For example, the keywords "haptic interface","haptic display","tactile display" were distilled into the keyword classes of "haptic" and "tactile" to capture the technological aspect of the keywords.
- In other cases, a keyword such as "tactile drawing" would be distilled into the 2 separate keyword classes of "tactile" and "drawing" as these parts indicated a technology and an activity respectively.

For Haptics venues:

- Keyword classes tended to be human activity-based, given that the community has been known to perform technological development not necessarily tied to any human activity.
- For example, the keywords "driving skill","driving assistance", "adaptive control", and "motion control" would be distilled into the keyword classes of "driving" and "control" in order to capture the interaction aspects of these keywords.
- In other situations, the entire original keyword was used as a keyword class. For example, the keywords "design parameter" and "design recommendations", were decided to be used as separate keyword classes despite the common presence of the "design" word among them.
- Our thought process for the above keyword classes was that "design parameters" indicated knowledge contributions of a technical implementation, while "design recommendations" could involve guidelines/advice for approaching an haptic application design process. Thus, these sorts of keywords were kept as separate keyword classes.

Thus, our mechanisms for deriving keyword classes generated different types of classes for comparison. Please refer to Chapter 5 (Results) for examples of keyword classes.

Additional Methodology - Stage 4 Step D -
Keyword Class Similarity Analysis Process

In order to identify how different communities shared/didn't share common keywords classes to describe haptic application design, a similarity analysis on each community's set of keyword classes was conducted. **This represents non-real data being analyzed. To see real similarity values, please refer to Chapter 5 (Results).**

Example

Step A | **Keyword Class Generation**

Highlighted Keyword Classes
aka parts of original keywords that seemed emblematic of haptic application design across different communities based on author judgement

Venue 1 Keywords
KW1 ASD
....
KW2 DEF
CW1 GHI
CW2 JKL
....
CW3 IOP
And many more

Venue 2 Keywords
KW1 DEF
....
SQ1 BNM
CW1 ASD
CW2 BNM
....
CW3 IOP
And many more

And for other venues as well

Keyword classes and associated paper counts across venues were collected in order to identify which classes were shared among different venues.

Example Keyword Classes	Venue 1	Venue 2	Venue 3	Venue 4	Venue 5	Venue 6
KW1	1	0	1	0	0	0
CW1	0	0	0	4	0	1
CW2	0	0	0	3	1	0
CW3	7	24	11	7	5	0
And many more from other venues						

These numbers were used for the calculation of similarity values below.

Details

The first author collected all keywords from each venue. Keywords that evoked haptic application design via technology or design oriented related words were highlighted (eg. HCI venues using haptic technology words, Haptic venues using human activity words). These words were then put into keyword classes (keyword parts emblematic of haptic application design) in order to allow for cross-community tallying of keyword occurrences.

Example

Step B | **Venue to Venue Keyword Class Similarity Calculations** * Non-real values are shown

	Venue 1	Venue 2	Venue 3	Venue 4	Venue 5	Venue 6
Venue 1	1	0.41	0.28	0.16	0.19	0.17
Venue 2		1	0.43	0.02	0.21	0.08
Venue 3			1	0.16	0.04	0.15
Venue 4				1	0.48	0.03
Venue 5					1	0.02
Venue 6						1

Calculating Similarity

Shared Keyword Classes Between 2 Venues : *Total Unique Keyword Classes of 2 Venues*

Venue 1 and Venue 2 Example

15 Shared Keyword Classes : 37 Unique Keyword Classes of 2 Venues

= 15 : 37 = 0.41

Details

In order to identify how different communities shared/didn't share common keyword classes in their metadata to identify haptic application design papers, a similarity analysis on each community's set of keyword classes represented by different venues was conducted.

Figure 4.11: Stage 4. An overview of deriving keyword classes and how they were analyzed for similarity. Real keyword data is not given. Please refer to the results for real data examples. Different colours represent different types of venue pairings. Higher saturation indicates higher similarity.

Chapter 5

Results

This chapter will describe the results of our scoping review. The ordering of the results will address each of our focal points and associated research questions described in Chapter 1 (Introduction) and Chapter 3 (Approach).

The results will be presented primarily as visualizations. We will interpret each visualization by highlighting the relevant focal points, research questions, and involved data required to interpret each visualization. These details will be preparatory to developing insights that will be detailed in Chapter 6 (Discussion).

In general, we will present visualized results that will compare community differences and similarities on haptic application design details such as the distributions of design energy, the design methods used, types of experiences/design reasons for using haptic technology, and how the communities described and viewed each other's approach to design.

5.1 Focal Point 1 Results

As a reminder, Focal Point 1 was defined as "Design Energy Distribution" where there was a curiosity in determining the differences/similarities of quantifiable design efforts put forth by the communities into the technical or experience design aspects of haptic application design. Additionally, we were curious whether design energies were changing at all in different years, or from different sized academic venues, which could imply changes in haptic application design approaches under different contexts.

Focal Point 1's research questions were the following:

> RQ1(a) What are the distributions of effort, which we will call design energy, put forth by the communities into the relevant technical, user experience, and method details of haptic application design?

RQ1(b) Have design energy distributions been changing under different circumstances?

RQ1(b i) Different on a community level?

RQ1(b ii) Different on different years?

RQ1(b iii) Different on different sized venues?

Chapter 4 (Methodology) elaborated upon the consultation of different community haptic experts, and their usage of a scoring system aimed to characterize how each community was detailing haptic application design. Please refer to Figure 4.8 for a reminder of our experts and their qualifications for this research.

The results of this section will cover how our experts collectively characterized different circumstances of design energy distributions, based upon our research questions in Chapter 1 (Introduction).

We will visualize the expert scores as visualized distributions by community, by different years, and by venue size. These address our research questions RQ1 (b i) to RQ1 (b iii) respectively.

Figure 5.1 illustrates the background of our Focal Point 1 results, reminding readers of the data source used by haptic experts to determine different distributions of design energies among the communities. The figure also provides a map of the different circumstances of design energy distributions that will be presented below.

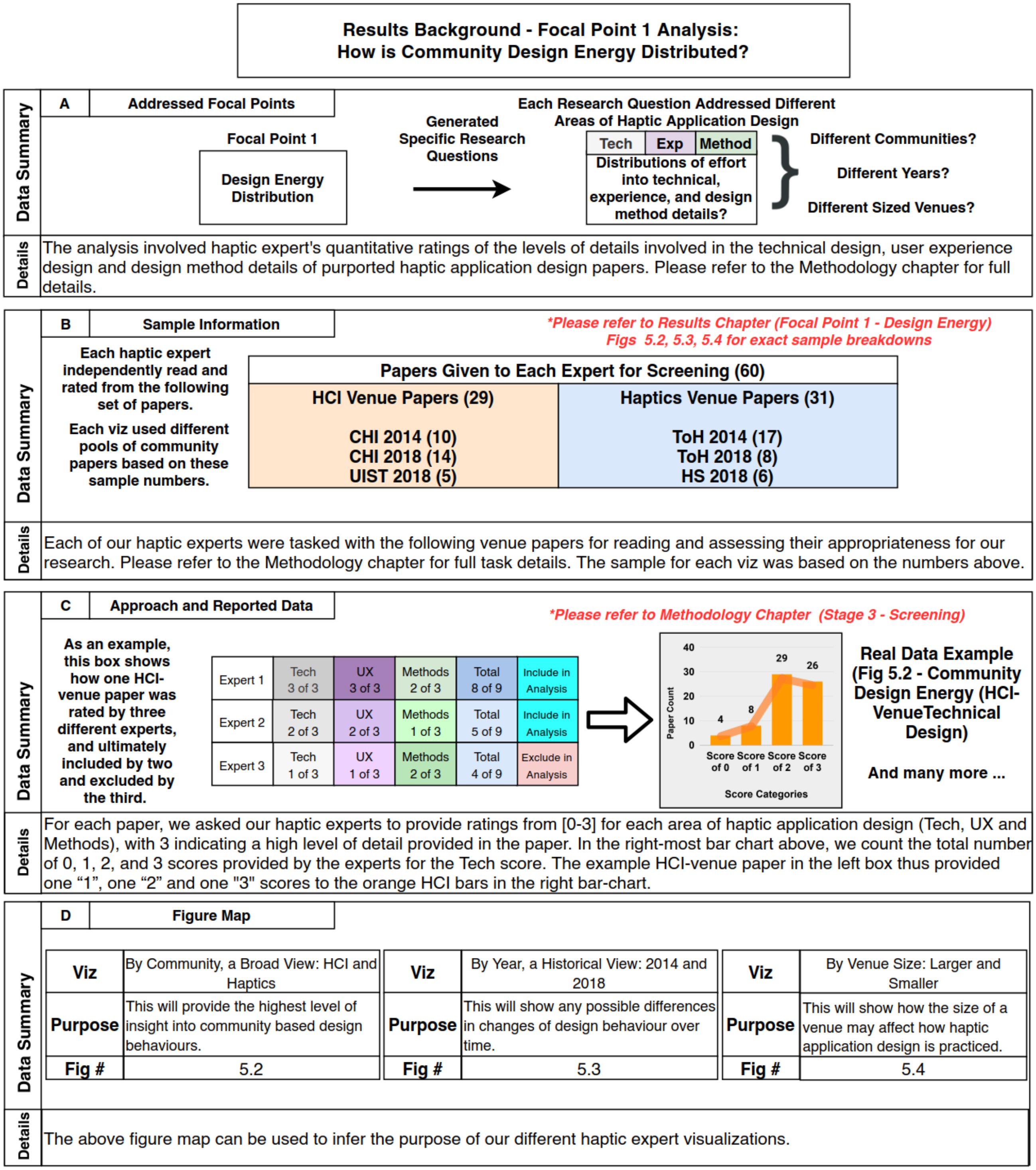

Figure 5.1: Data summary of our community design energy analysis.

How to Read Focal Point 1 Visualizations - For each visualization seen in this section below, please note the following:

1. Paper count (the number of papers that fell under a specific rating category) are

reported as the y-axis of the figures described in Fig 5.2, 5.3, and 5.4.

2. Different colours indicate different communities.

3. Trendlines indicate the general pattern (shape) indicated by the distribution.

4. Visualizations report on the 46 expert verified (included) papers based on the output of Stage 3 Step 3B.

5. Score categories represent differences in the levels of detail provided by a community, where higher score categories indicate higher levels of details being provided.

6. Each visualization will use different sample groups to represent specific circumstances of RQ1 (b i) to RQ1 (b iii). The visualization header will specify which sample groups are involved.

7. For each visualization, the relevant sample sizes are reported in the top portion. These represent the sum of count of papers approved by each expert for a particular data view (e.g. "By Community" would consider all venues/years). All experts worked from the same pool of 60 candidate papers described in Step 3A of our methodology. However, each view covered different pools of community papers based on these 60 candidate papers (e.g. 29 HCI papers, 31 Haptics papers for the community view). Additionally, each expert had discretion over how many papers they approved, and we captured this diversity by summing their individual approval counts. For example, in Fig 5.2, the final sample size of 67 HCI papers was due to the summation of 21, 24, and 22 approved papers from Experts 1 to 3 respectively. In other words, each expert approved different amount of papers from the pool of 29 HCI papers available in the community view. Each visualization will denote the pool sizes, and other relevant sample information in the top portion of the figure.

8. **Percentages Are Not Reported.** These results report paper counts, not as percentages. We wanted to emphasize any possible disparities/gaps between the heights of different score categories which are computed on different bases. Thus, a percentage would distort these true differences.

We also visualized expert ratings to show the distributions of included and excluded papers. This was to help identify what details pushed a community's set of papers into being considered appropriate for haptic application design analysis. These distributions can be seen in the Appendix section.

Interpretation Example - Please refer back to Figure 4.9 for a reminder of the haptic expert's scoring system used to characterize the levels of details given in each area of haptic application design. Suppose an HCI community set of venues (eg. CHI 2014/2018) displayed higher occurrences of the Score 3 category within technical design compared to the Haptics community venues. This could be interpreted as the HCI community prioritizing technical haptic details.

If the HCI community displayed high occurrences of lower score categories (eg. 0 and 1) in design areas such as experience design in the excluded paper score distribution, this could be interpreted as the community placing lower value in providing such details. Figures that display excluded paper score details can be seen in the Appendix chapter.

5.1.1 Focal Point 1 Results - By Community, a Broad View: HCI and Haptics

At the top of the following figures, "Papers Rated By Experts" indicates the total papers given to the haptic experts for rating, for each community's venues (total 60). "Total Approvals" sums the papers approved by each haptic expert, for a combined total greater than those that were rated. Note that low ratings can appear (at a lower expected frequency than the higher ratings) because a given expert could provide at least one lower rating but still approve that paper. If a given expert did not approve a paper, their ratings for that papers are not included here.

Figure 5.2 represents how the communities behaved differently/similarly in haptic application design. The figure grouped all HCI venues against all Haptics venues used in our study.

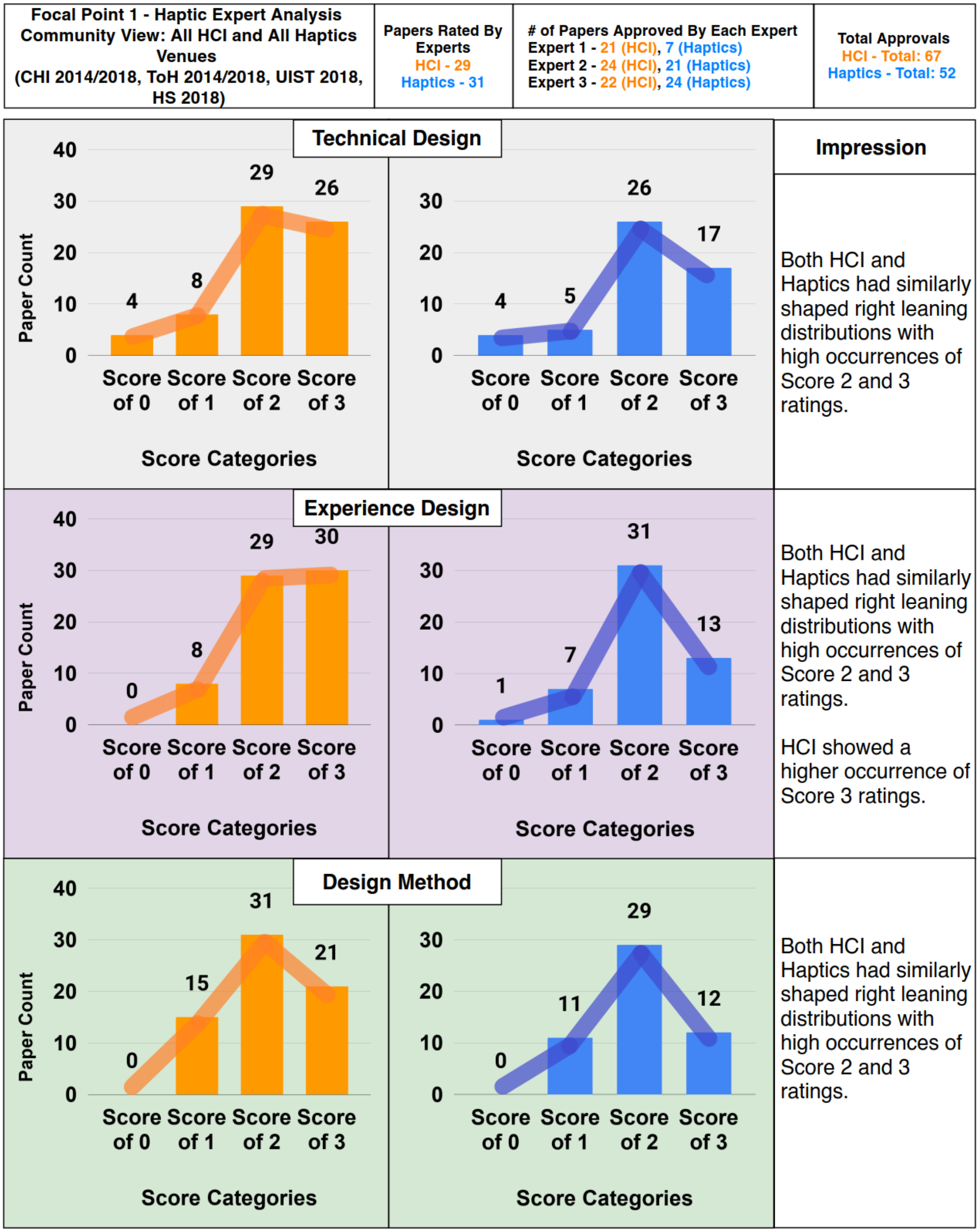

Figure 5.2: Distribution of haptic experts' ratings of their approved papers from HCI and Haptics venues, for three aspects of haptic application design. This figure shows the distribution of ratings based on all of the HCI and Haptics venue papers given to experts.

Overall Impressions - Both communities were rated similarly on almost all areas of haptic application design. This can be seen in the similarly shaped trendlines among the different haptic application design areas in the top section of Figure 5.2.

Experience design was an exception, where the HCI community had higher occurrences of Score 3 rating category (30) over the Haptics community (13).

Thus, we are left with an impression that the HCI community may prioritize experience design details slightly more than the Haptics community.

5.1.2 Focal Point 1 Results - By Year, a Historical View: 2014 and 2018

Please note that the venues analyzed were only CHI 2014/2018 and ToH 2014/2018. There were no 2014 iterations for UIST and HS in which a comparison could be made. Please refer to Chapter 4 (Methodology) for justifications on this matter.

Figure 5.3 represents both a baseline view (2014) in which future venues (2018) can be used to detect any changes in haptic application design patterns.

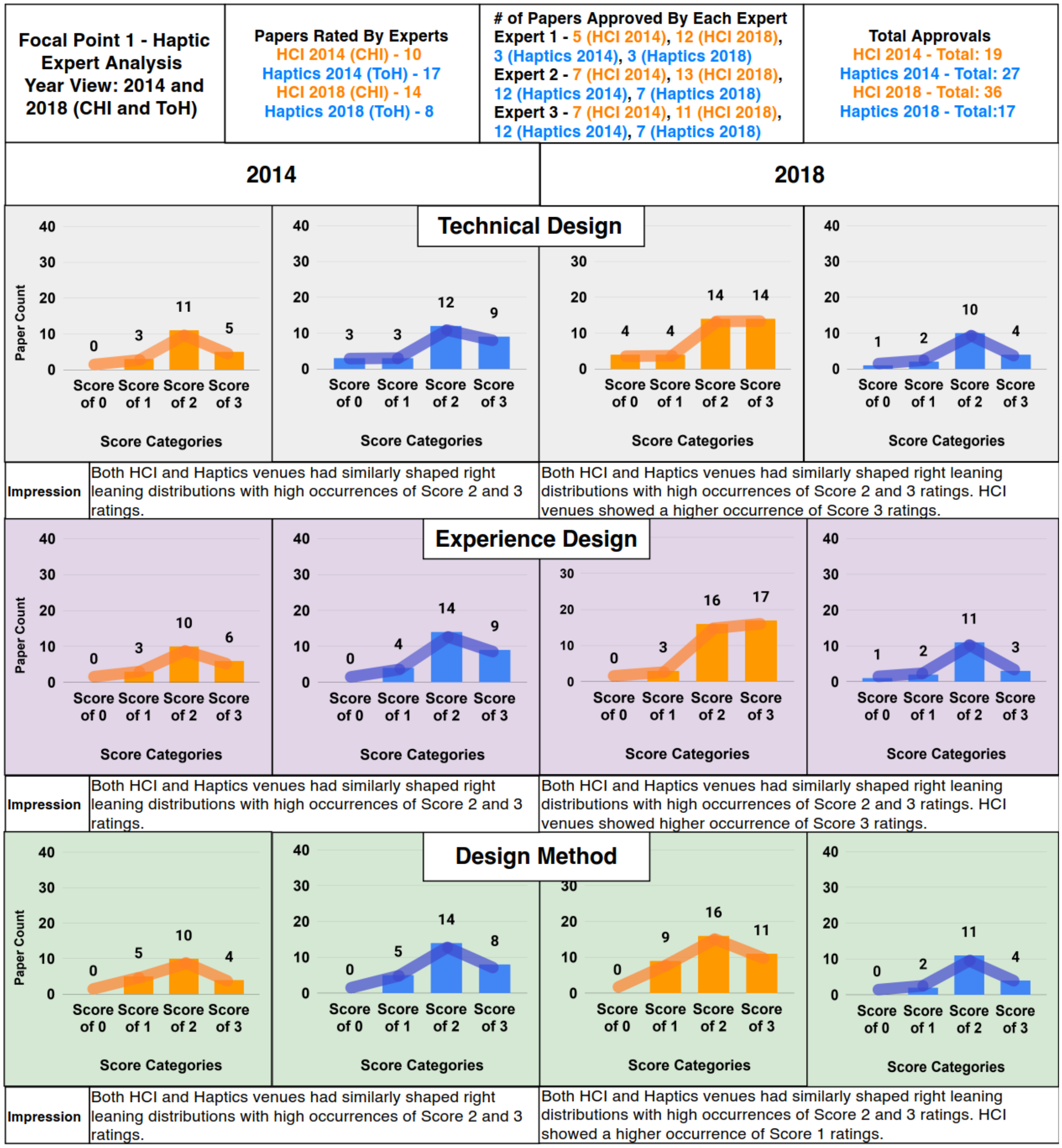

Figure 5.3: Distribution of haptic experts' ratings of their approved papers from HCI and Haptics venues, for three aspects of haptic application design. This figure shows the distribution of ratings based on 2014 and 2018 HCI and Haptics venue papers given to experts.

Overall Impressions - In 2014, both communities were rated similarly on all areas of haptic application design. This was even the case for experience design ratings.

By contrast in 2018, a growth in the HCI community could be seen in all areas of haptic application design. This can be seen as higher occurrences of the Score 3 rating category. For example, in 2018‘s technical design, HCI showed 14 occurrences over Haptics’ 4 occurrences. In 2018’s experience design, HCI showed 17 occurrences over Haptics’ 3 occurrences. In 2018’s design methods, HCI showed 11 occurrences over Haptics’ 4 occurrences.

2014 indicated the beginning of a trend in which both communities seemed comparable in all areas of haptic application design. However in 2018, both communities exhibited different types of growth in different areas of haptic application design.

The HCI community showed the biggest change among the higher score categories of different haptic application design areas.

5.1.3 Focal Point 1 Results – By Venue Size: Larger and Smaller

Figure 5.4 represents the community design patterns of the bigger sized venues (based on sample size). This view can be compared against the smaller sized venues in order to denote any differences/similarities in design patterns.

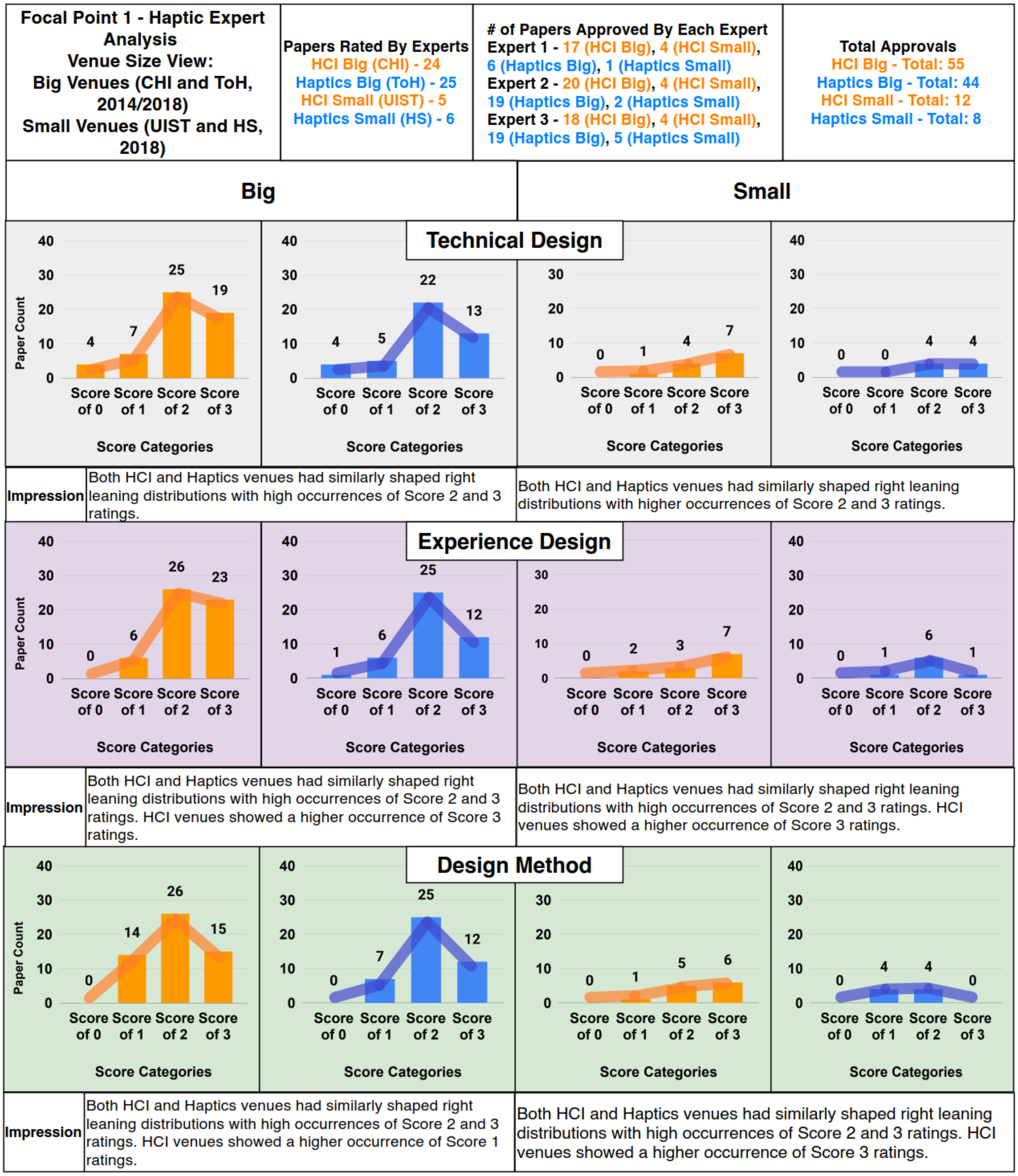

Figure 5.4: Distribution of haptic experts' ratings of their approved papers from HCI and Haptics venues, for three aspects of haptic application design. This figure shows the distribution of ratings based on the big and small sample size HCI and Haptics venue papers given to experts.

Overall Impressions - For the big venues, both communities were rated similarly on all areas of haptic application design. Similar to the community view, the HCI community prioritized experience design details. This is indicated by the higher occurrences of the Score 3 rating category (23) over the Haptics community's occurrences (12).

For the small venues, the HCI community had high occurrences of the Score 3 rating category in technical design (7), experience design (7) and design methods (6). By comparison, the Haptics community had lower occurrences of the Score 3 rating category in technical design (4), experience design (1) and design methods (0).

The big venue patterns suggested that the HCI community prioritized experience design details. The smaller community venues behaved somewhat differently than the bigger venues. The HCI community seemed to provide more details in all haptic application design areas.

5.2 Focal Point 2 and Focal Point 3 Results

Focal Point 2 was defined as "Purpose of Haptics in User Experience" where we wanted to understand the different community purposes of using haptic technology to support specific user experiences. Focal Point 3 was focused on"Design Methods Used to Create Haptic Application" where we wished to characterize the specific design methods used in the technical and experience design areas of haptic applications.

Focal Point 2's research questions consisted of the following:

RQ2(a) Who are the typical users being targeted for haptic support?

RQ2(b) What are the design reasons for using haptics to support these users?

Focal Point 3's research questions consisted of the following:

RQ3 What are the typical techniques and considerations used by the communities in practicing the technical and user experience aspects of haptic application design?

Chapter 4 (Methodology) described our qualitative analysis process in deriving codes to describe community design practices, types of user experiences, and associated reasons for the usage of haptic technology.

The results of this section will visualize the distributions of our qualitative codes. Figure 5.5 illustrates the background of our Focal Point 2 and 3 results, reminding readers of the data sources involved in our qualitative analysis. The figure also provides a map of the different aspects (RQ2a/b and RQ3) of haptic application design practices and user application considerations being visualized.

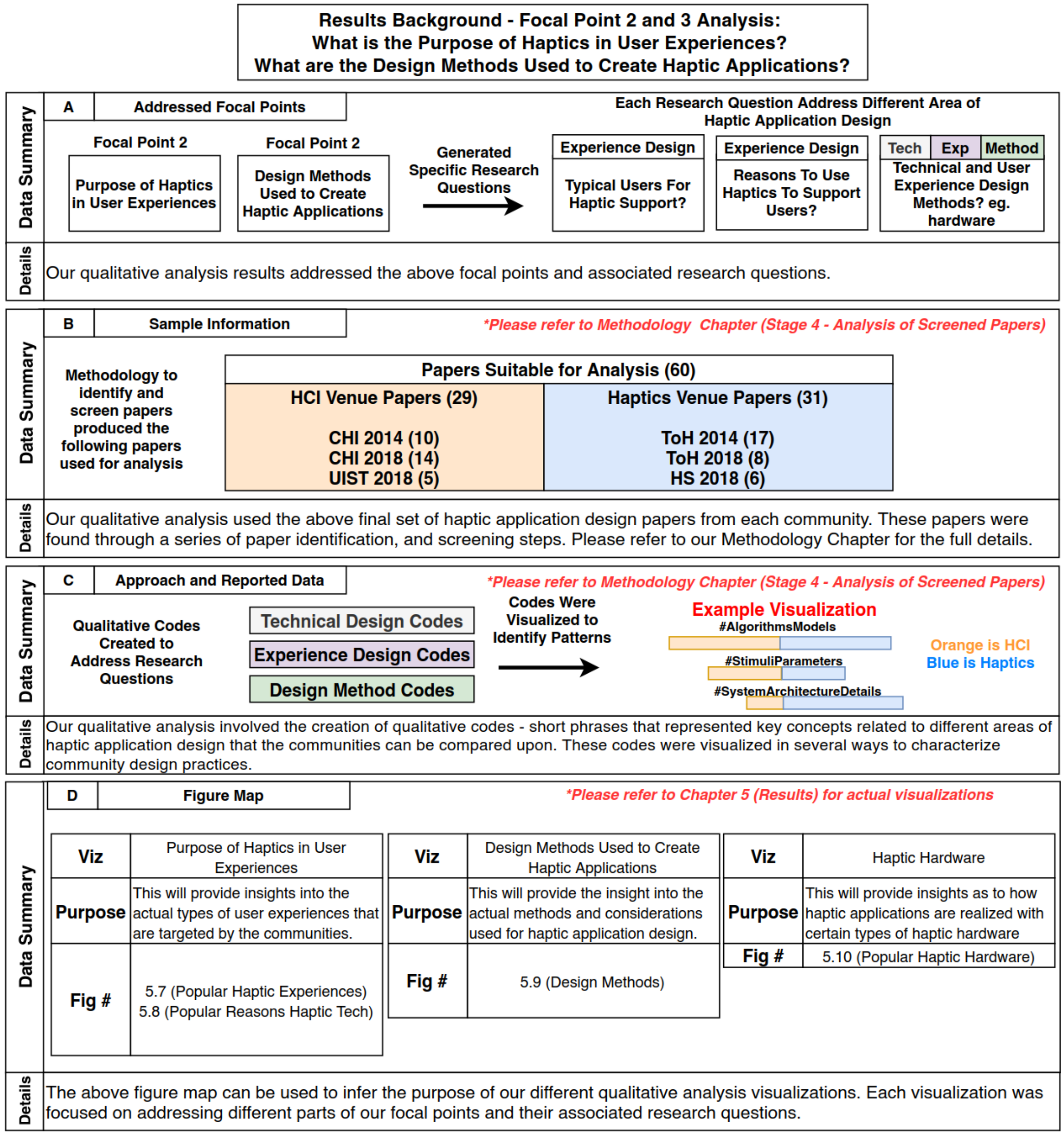

Figure 5.5: Data summary of our qualitative analysis.

How to Read Focal Point 2/3 Visualizations - For each distribution visualization seen in this section below, please note the following:

1. **The percentage of papers exhibiting a qualitative code is reported.** We decided to use percentages as we wanted to compare how each qualitative code was used among the differently sized sets of community papers. The uneven community samples were a byproduct of our screening methods described in Chapter 4 (Methodology).

2. **Percentages when added up for a community may exceed 100%.** This is due to papers having multiple applicable qualitative codes.

3. Different colours indicate different communities.

4. We provide initial impressions of the data, without jumping into full discussion.

5.2.1 Qualitative Code Definitions

As described in Chapter 4 (Methodology), the generation of our qualitative codes involved much iteration and clustering in order to find the most succinct and applicable codes across both community's set of verified haptic application design papers.

Figure 5.6 details the codes and their definitions displayed in our distributions below.

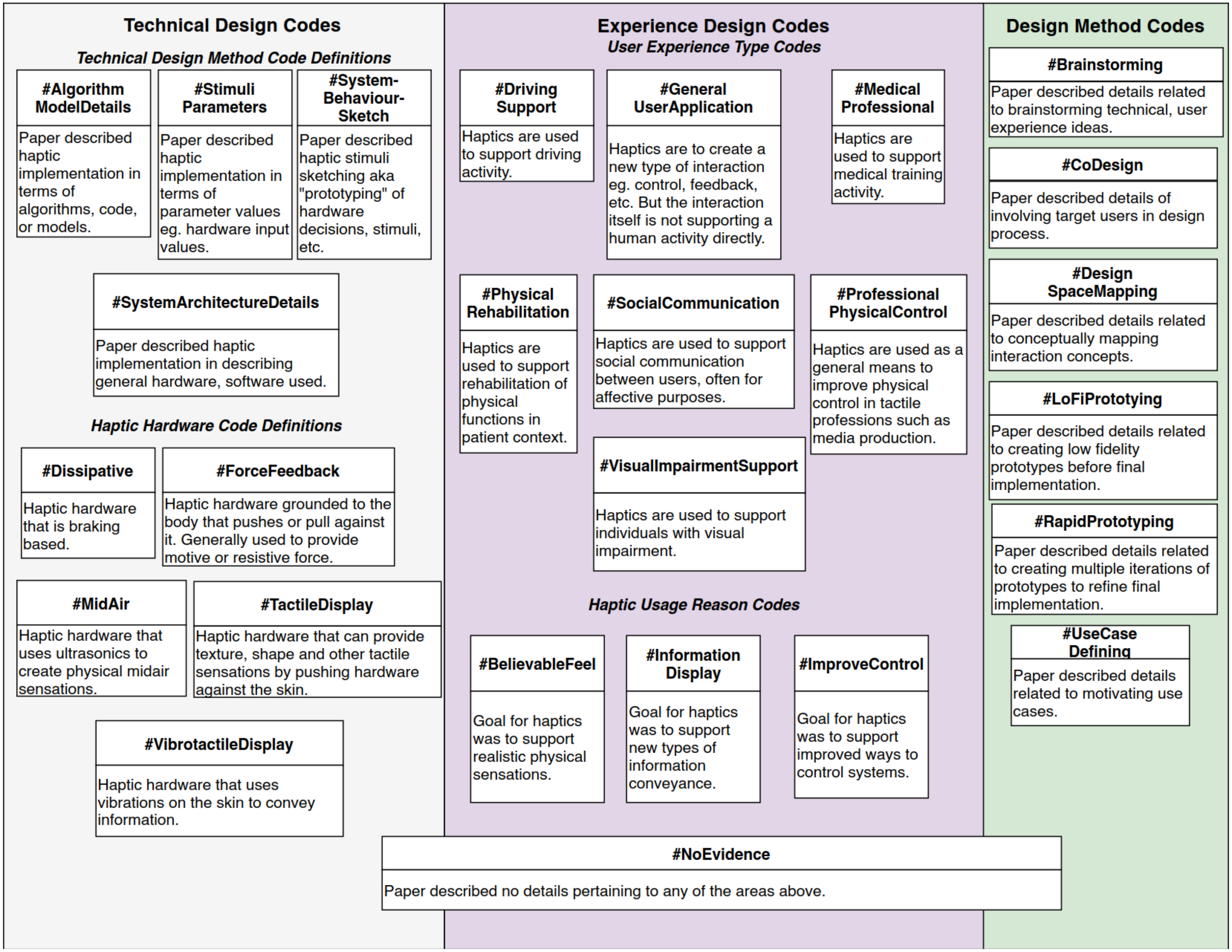

Figure 5.6: All of the codes and definitions used in our qualitative analysis.

5.2.2 Focal Point 2 Results - Popular Haptic Experiences and Reasons for Haptic Technology Usage

Popular Haptic Experiences

Figure 5.7 shows the results of our qualitative analysis of the popular haptic user experiences categories supported by the communities.

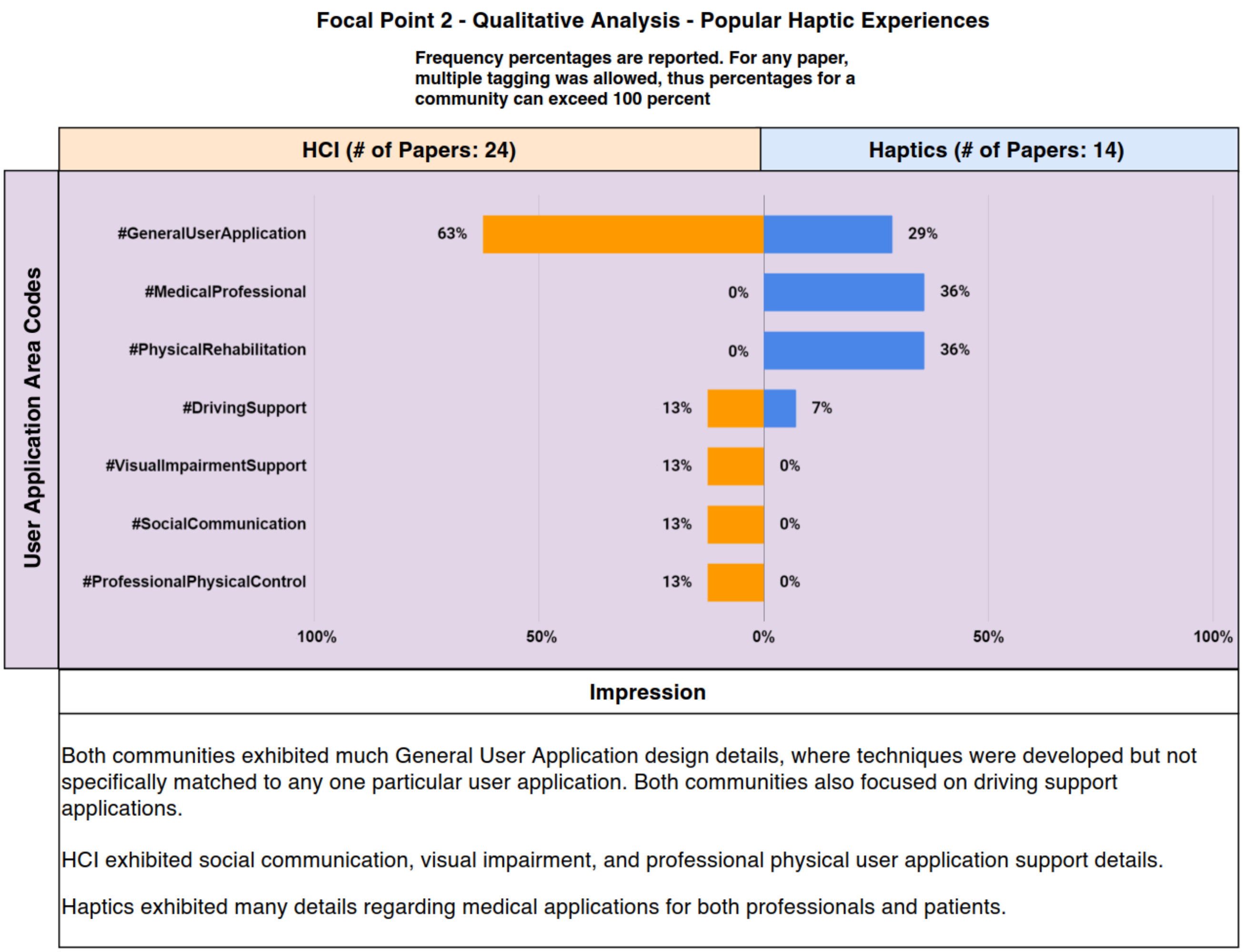

Figure 5.7: How each community emphasized certain user application categories supported by haptic technology.

Overall, there is an impression that the communities had different preferences in the types of user applications being designed.

The HCI community supported applications for social communication (13%), visual impairment (13%), and professional physical user control (13%).

Meanwhile, the Haptics community supported medical related applications such as medical professional support (36%) and physical rehabilitation (36%).

Only driving applications shared any occurrences between the communities. The HCI community exhibited 13% of papers detailing driving support, while the Haptics community exhibited 7%.

Popular Reasons for Haptic Technology Usage

Figure 5.8 shows the results of our qualitative analysis on the popular reasons for haptic technology usage in supporting user experiences.

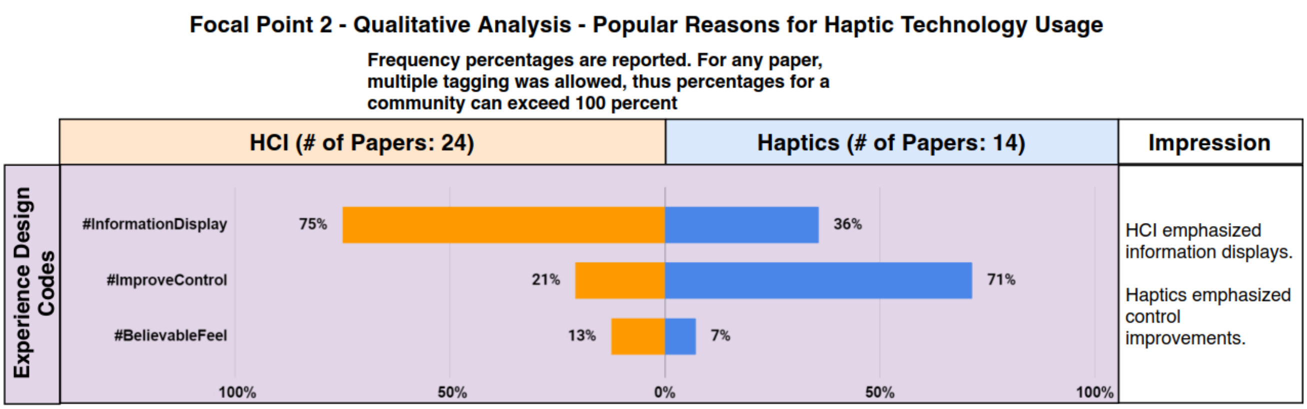

Figure 5.8: How each community emphasized specific reasons for designing with haptic technology.

The types of designed user experiences was notably different among the communities.

The HCI community emphasized haptic technology as a form of information display (75%).

The Haptics community emphasized haptic technology as a means to improve physical control (71%).

5.2.3 Focal Point 3 Results - Popular Design Methods Used to Create Haptic Applications

Figure 5.9 shows the results of our qualitative analysis on the popular design practices seen in different areas of haptic application design - technical design, experience design, and design methods.

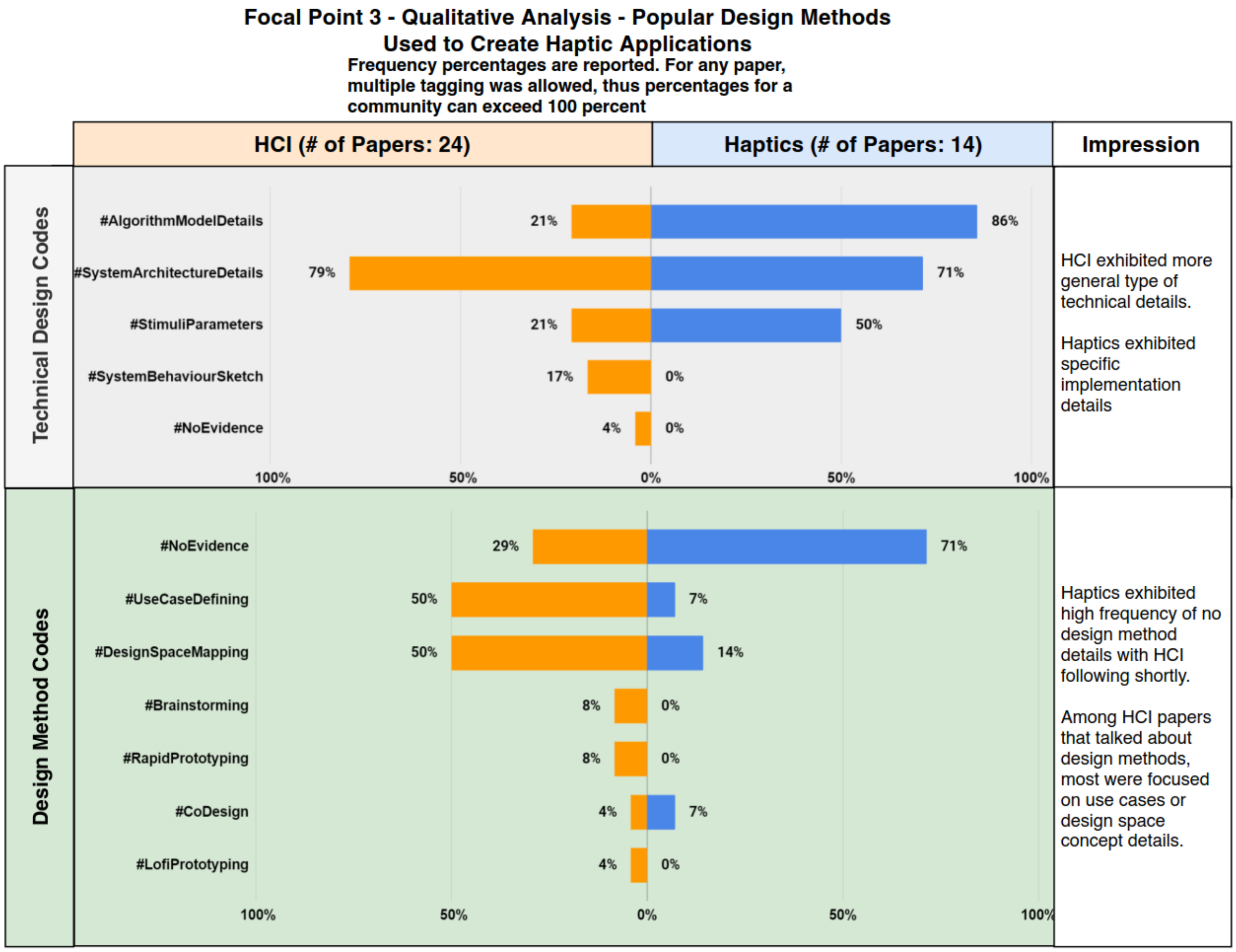

Figure 5.9: How each community emphasized identified design practices in each area of haptic application design.

Overall, there is an impression that the communities emphasized design practices very differently.

For instance, the HCI community reported general system architecture details (79%). Meanwhile, the Haptics community reported a variety of technical design details such as algorithms (86%) and stimuli parameters (50%). To clarify, general system architecture details described technical details that generally listed the names of the hardware/software being used, but did not specify how these were used to implement haptic experiences. Meanwhile, algorithms and stimuli parameters provided the descriptive step by step actions that hardware/software should take to create a target haptic sensation.

As Figure 5.7 reported, the types of designed user experiences was notably different among the communities. In terms of the design methods being reported, the Haptics community typically did not report any method details (71%). The HCI community reported use cases (50%) and design spaces for haptic applications (50%).

Popular Types of Haptic Hardware

Figure 5.10 shows the results of our qualitative analysis of the prevalence of popular haptic technologies used in the technical design of haptic applications.

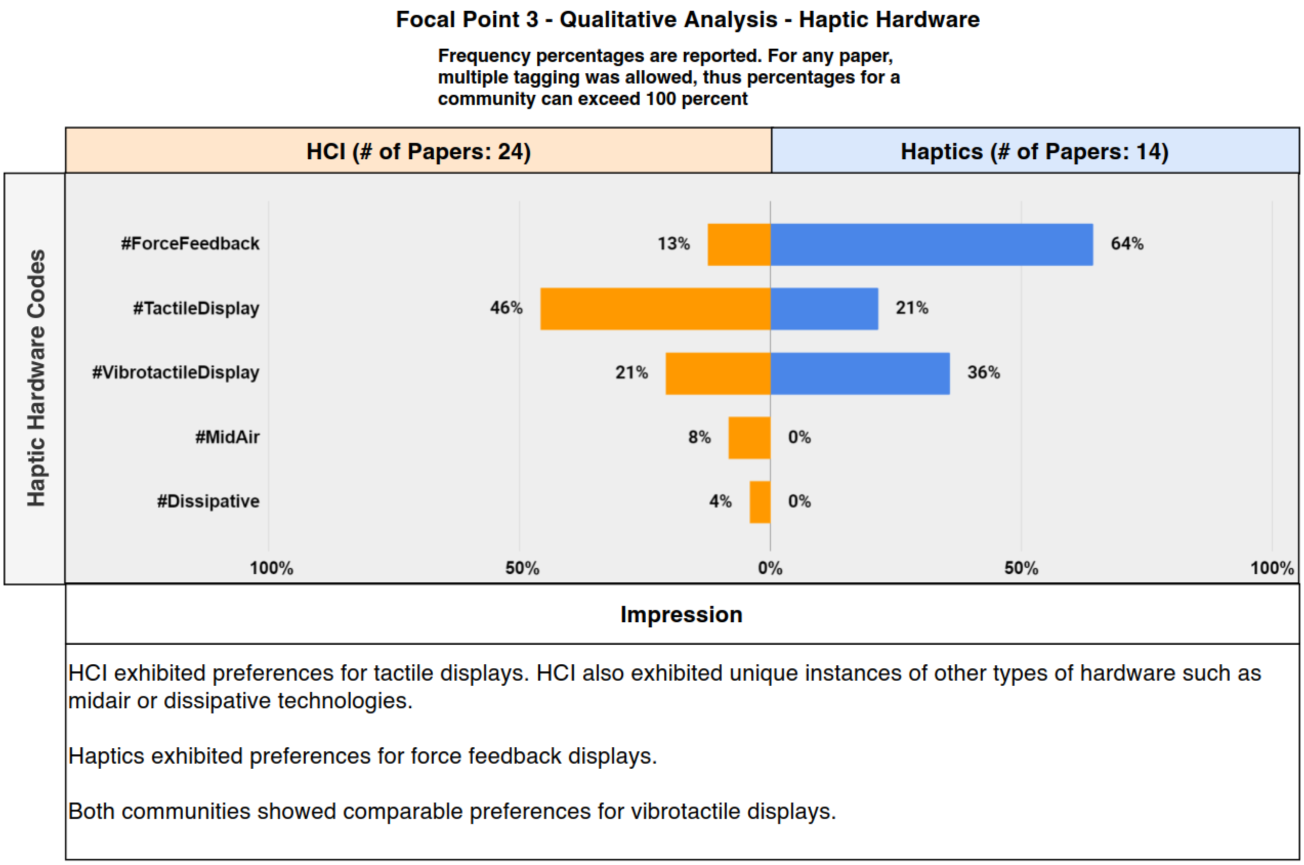

Figure 5.10: How each community emphasized certain haptic hardware to create haptic applications.

Overall, there is an impression for different preferences of haptic hardware among the communities.

The HCI community showed a strong preference for tactile display technologies (46%).

The Haptics community exhibited a strong preference for force feedback displays (64%).

Interestingly, both communities showed strong interest in vibrotactile display technologies. The HCI community showed a preference of 21%, while the Haptics community had a preference of 36%.

5.3 Focal Point 4 Results

Focal Point 4 was focused on "Understanding Community Perspectives on Haptic Application Design" where we we wished to uncover the differences or similarities in how the communities described haptic application design. These could be uncovered by looking at the language or words used by each community on describing haptic application design concepts. Additionally, we recruited the help of three community representative haptic experts and collected their ratings of the different levels of details provided by the communities on haptic application design areas.

Focal Point 4's research questions were the following:

> RQ4(a) How does each community self-report their haptic application design activities, through the lens of their publications' keywords?
>
> RQ4(b) How do practitioners representing the communities view haptic application design practices? Do they interpret each community's published technical, user experience, and method details similarly or differently?

Chapter 4 (Methodology) described how we analyzed the different community keywords used to describe haptic application design papers. It was mentioned that similarity metrics, calculated by the proportion of the shared keyword classes between two venues, were created to help understand the degree of similarity in community descriptions of haptic application design. We also described how the experts used a scoring system to independently characterize how each community was detailing different areas of haptic application design.

The results of this section will cover the different similarity values of all pairings of our community venues. The results will also cover each expert's respective haptic application design scoring patterns on the technical, experience design, and design method score distributions used to address Focal Point 1.

How to Read Focal Point 4 Visualizations

Community Keyword Similarity Table Visualization

1. A table of similarity values (proportion of shared keyword classes between two venues) will be shown. This can be seen in Figure 5.11. The keywords were found in Stage 2 of our methodology.

2. Higher similarity values indicate higher number of shared keywords between two venues. Higher saturation will also be used in these cases.

3. Different colours are also used to denote the different communities.

Haptic Expert Rating Pattern Visualizations

1. Each expert's rating patterns are shown side by side.

2. Paper count (the number of papers that fell under a specific rating category) are reported as the y-axis of the figures described in Fig 5.14

3. Different colours indicate different communities.

4. Trendlines indicate the general pattern (shape).

5. Score categories represent differences in the levels of detail provided by a community, where higher score categories indicate higher levels of details being provided.

6. We provide initial impressions of the data, without jumping into full discussion.

7. **Percentages Are Not Reported.** These results report paper occurrences as hard counts, not as percentages. We wanted to emphasize any possible disparities/gaps between the heights of different score categories.

5.3.1 Focal Point 4 - Similarity of Words to Describe Haptic Application Design

As a reminder, keyword classes were author simplified representations of the original longer keywords that were thought to indicate an aspect of haptic application design. We chose the keywords classes specifically for each community, based on our interpretations of which words implied haptic application design in the context of that community. Please refer to Stage 2 Step 2B of Chapter 4 Methodology for the thought process behind the creation of keyword classes.

Figure 5.11 details our calculated similarity values for every pair of venues. These similarity values can be considered as the proportion of a venue pair's shared keyword classes over the total unique keyword classes of the venue pair. Please refer back to Fig 4.11 for details as to how keyword similarity values were calculated.

Figure 5.12 displays the shared keyword classes found between every pairing of community venues. This will be useful in seeing the specific types of keyword classes that are common/different between the HCI and Haptics communities. In Fig 5.12, the values in the cells represent the number of papers of a given venue-year that contained the keyword class. The keyword classes listed for each comparison box were identified as common to the two listed venue-years. For example, although the left-hand boxes show CHI 2014, the keyword class list differs because CHI 2014 shared different keywords with CHI 2018 than with UIST 2018. Also seen in Figure 5.12, the list of shared keyword classes are shorter for cross-community comparison boxes than for comparisons within a community.

Focal Point 4 - Understanding Community Perspectives on Haptic Application Design - Keyword Class Similarity Analysis Results

In order to identify how different communities shared/didn't share common keyword classes to describe haptic application design, a similarity analysis on each community's set of keyword classes was conducted. **This represents real data results. Please refer to the Methodology chapter for details on how keyword class similarity values were calculated.**

Results

Venue to Venue Keyword Similarity Value Results

	CHI 2014	CHI 2018	UIST 2018	ToH 2014	ToH 2018	HS 2018
CHI 2014	1	0.26	0.35	0.01	0.02	0.00
CHI 2018		1	0.17	0.01	0.04	0.02
UIST 2018			1	0.01	0.02	0.00
ToH 2014				1	0.15	0.06
ToH 2018					1	0.09
HS 2018						1

Description

In order to identify how different communities shared/didn't share common keyword classes in their metadata to identify haptic application design papers, a similarity analysis on each community's set of keyword classes represented by different venues was conducted.

Figure 5.11: The results of our keyword similarity analysis. Orange represents HCI comparisons. Blue represents Haptics comparisons. Green represents cross-community comparisons. Higher saturation indicates higher similarity. Please refer to Fig 4.11 for similarity value calculation details.

CHI 2014 and CHI 2018 7 Keyword Classes Are Shared	CHI 2014	CHI 2018
actuated	2	2
force	4	7
haptic	7	24
pressure	3	1
shape	6	12
touch	15	10
tactile	3	13

CHI 2014 and UIST 2018 6 Keyword Classes Are Shared	CHI 2014	UIST 2018
actuated	2	1
haptic	7	11
shape	6	2
skin	1	2
touch	15	4
tactile	3	3

CHI 2014 and ToH 2014 1 Keyword Class Is Shared	CHI 2014	ToH 2014
tactile	3	4

CHI 2014 and ToH 2018 1 Keyword Class Is Shared	CHI 2014	ToH 2018
tactile	3	8

CHI 2014 and HS 2018 0 Keyword Classes Are Shared	CHI 2014	ToH 2018
None Shared	N/A	N/A

CHI 2018 and UIST 2018 5 Keyword Classes Are Shared	CHI 2018	UIST 2018
actuated	2	1
haptic	24	11
shape	12	2
tactile	13	3
touch	10	4

CHI 2018 and ToH 2014 1 Keyword Class Is Shared	CHI 2018	ToH 2014
tactile	13	4

CHI 2018 and ToH 2018 2 Keyword Classes Are Shared	CHI 2018	ToH 2018
tactile	13	8
vibrotactile	4	1

CHI 2018 and HS 2018 1 Keyword Class Is Shared	CHI 2018	HS 2018
wearable	2	1

UIST 2018 and ToH 2014 1 Keyword Class Is Shared	UIST 2018	ToH 2014
tactile	3	4

UIST 2018 and ToH 2018 1 Keyword Class Is Shared	UIST 2018	ToH 2018
tactile	3	8

UIST 2018 and HS 2018 0 Keyword Classes Are Shared	UIST 2018	HS 2018
None Shared	N/A	N/A

ToH 2014 and ToH 2018 10 Keyword Classes Are Shared	ToH 2014	ToH 2018
cues	2	1
driving	3	1
game	1	1
haptic interaction	2	4
human computer interaction	6	1
human factors	6	5
signals	1	1
surgical	2	2
tactile	4	8
training	5	2

ToH 2014 and HS 2018 4 Keyword Classes Are Shared	ToH 2014	HS 2018
human computer interaction	6	1
rehabilitation	16	1
surgical	2	1
training	5	2

ToH 2018 and HS 2018 4 Keyword Classes Are Shared	ToH 2018	HS 2018
human computer interaction	1	1
skill	2	1
surgical	2	1
training	2	2

Figure 5.12: Keyword class appearances for all analyzed venue pairs. Positioning and colour scheme intentionally resembles Fig 5.11 for consistent visual language. However, the saturation scheme is not implemented in this figure.

HCI Venue Keyword Similarity Analysis - Based on the similarity value table in Fig 5.11, the HCI community is more similar to each other than with Haptics venue combinations. The HCI venue pairings showed an average similarity value of 0.26.

Haptics Venue Keyword Similarity Analysis - For Haptics community venue combinations, the resulting average similarity value was 0.10. This lower value maybe attributable to less consistent keyword classes being used by the Haptics venues.

Cross-Community Venue Keyword Similarity Analysis - Typically, HCI community and Haptics community combinations had an average similarity value of 0.01.

Overall Keyword Class Similarity Analysis Impressions
After the main author manually derived and analyzed the similarity of keyword classes according the process described in Section 4.64, the resulting average keyword class similarity values suggested low commonality in the language shared between the HCI and Haptics communities.

Possible Explanation for Low Cross-Community Keyword Class Similarity
As indicated by the shared keyword classes represented by Fig 5.12, we found that our HCI-venue keyword classes often referred to technology-based words, while Haptics-venue keyword classes referred to activity-based words. For example, the HCI-venue keyword classes used technology-based words such as "actuated" or "tactile". The Haptics-venue keyword classes used activity-based words such as "surgical" or "training". Thus, the nature of the types of keyword classes appeared to be different for each community which may explain the low cross-community similarity value.

The low cross-community keyword class similarity value could also be attributed to the diverse nature of the Haptic-venue's activity-based keyword classes. When looking at the keyword classes shared between ToH 2014/2018 and HS 2018 in Fig 5.12, certain ToH activity-based keyword classes such as "driving" or "game" did not appear in HS 2018. This may have also led to the Haptics community's lower within community average keyword similarity value. Compared with the technology-based keyword classes used in the HCI venues, many keyword classes such as "actuated", "haptic", and "tactile" occurred more consistently throughout all HCI venues.

5.3.2 Focal Point 4 - Common Words Used to Describe Haptic Application Design

Figure 5.13 shows the most popular shared keyword classes within the HCI, Haptics, and across both communities.

Popular HCI Keyword Classes	Total # Papers Across All HCI Venues
1. haptic	42
2. touch	29
3. shape	20
4. tactile	19
5. actuated	5

Popular Haptic Keyword Classes	Total # Papers Across All Haptic Venues
1. training	9
2. human computer interaction	8
3. surgical	5

Popular Cross Community Keyword Classes	Total # Papers Across Different Venues
***1. Tactile	31

*****Please note that this keyword class had no occurrences in HS 2018.**

However, since this was the only venue with no occurrences, this remained the stronger keyword class to report.

Other keyword classes across communities did not consistently report keyword classes across different community venues.

Figure 5.13: Popular keyword classes among the communities. Keyword classes are general terms derived from original keyword data via analysis.

For the HCI community, we found "haptic" to be the most frequently occuring keyword class for the haptic application papers that our overall process identified.

For the Haptics community, our process identified "training" as the most frequently occurring keyword class to indicate haptic application design papers.

Across communities, "tactile" was the most common keyword class that was identified by our process in connecting the communities on describing haptic application design.

5.3.3 Focal Point 4 – Haptic Expert Rating Patterns

As described in Chapter 4 (Methodology), each haptic expert was tasked to independently rate haptic application design areas for 60 potential haptic application design papers. Figure 5.14 compares each expert's respective rating pattern in order to draw ideas of whether the communities viewed haptic application design practices similarly or differently.

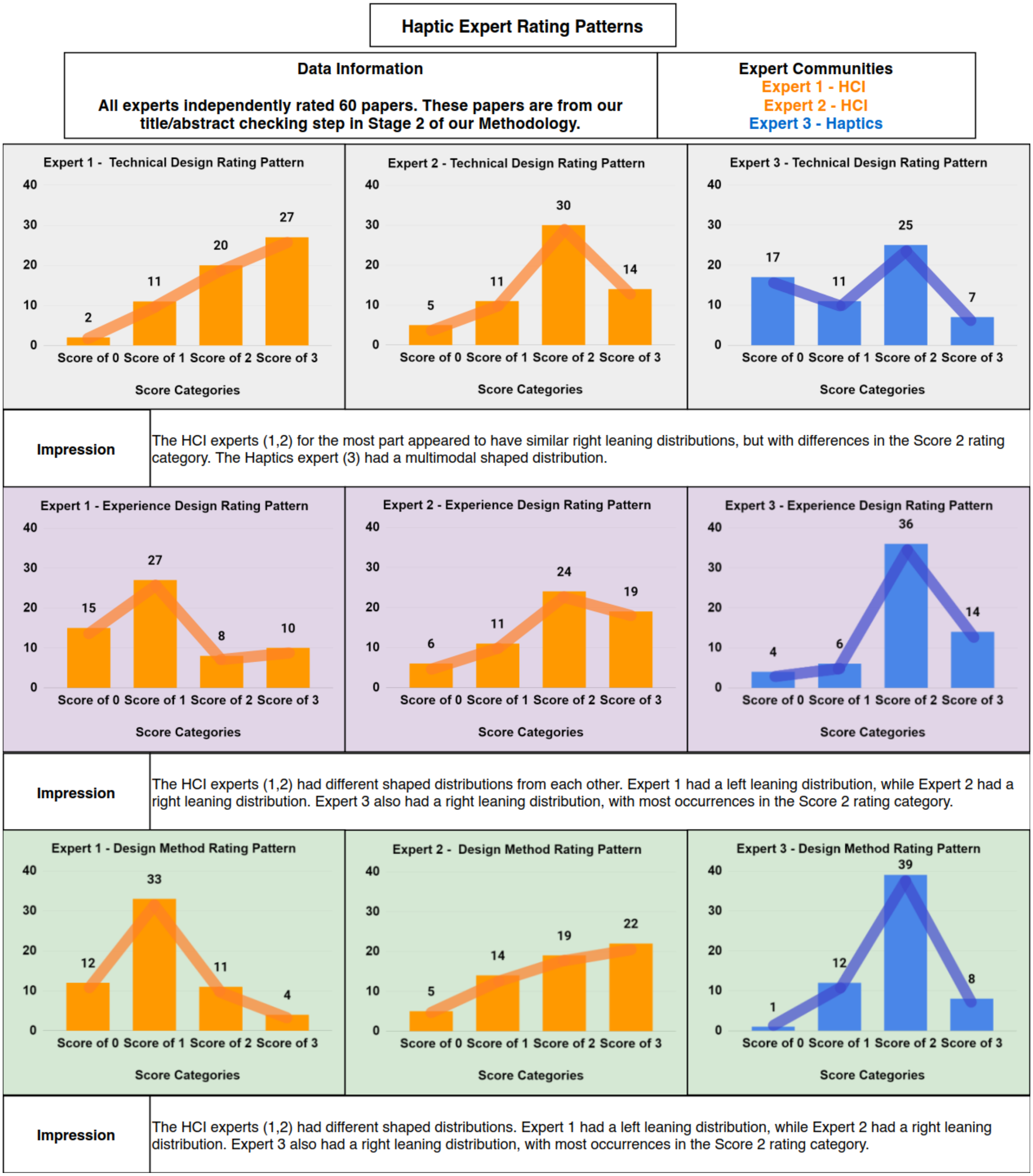

Figure 5.14: Each expert's rating pattern for each haptic application design area.

Technical Design Rating Comparison - Among technical design ratings, the HCI experts (1 and 2) appeared to rate technical design details favourably. This was indicated by the similiar trendline shapes for 1 and 2 in Figure 5.14. But the Haptics expert (3) had more variance in their ratings, possibly due to their technical background causing a discerning eye for technical details. This was indicated by Expert 3's multimodal trendline shape in Figure 5.14.

Experience Design Rating Comparison - Among experience design ratings, the HCI experts seemed to have opposite views. Expert 1 rated experience design details of papers to be generally lower, indicated by the left leaning score distribution caused by higher occurrences Score 0 and 1 ratings. Meanwhile, Expert 2 and Expert 3 shared similar rating patterns, where they both viewed papers to generally hold good experience design details. This was indicated by the right leaning distributions of Experts 2 and 3, caused by higher occurrences of Score 2 and 3 ratings.

Design Method Rating Comparison - Among design method ratings, a similar pattern of disparate HCI expert views was seen again. Expert 1 rated design method details to be quite lower than Expert 2, as indicated by Expert 1's left leaning distribution, caused by higher occurrences of Score 1 ratings. Expert 2 seemed to show a more even distribution of detail ratings, as indicated by a "steady" right leaning distribution shape, caused by high occurrences of Score 1, 2, and 3 ratings. However, Expert 3 viewed most papers to hold a good level of design method details, indicated by the spike in the Score 2 rating category.

Inter-rater Reliability - Krippendorff's alpha was used to assess the inter-rater reliability among our experts on the 3 areas of haptic application design [48]. For each area of haptic application design, each expert's ratings of the 60 candidate haptic application design papers were used to calculate Krippendorff's alpha. In other words, 180 data points (60 ratings of a given haptic application design area for 3 experts) were used to calculate 3 different alpha values.

For each area of haptic application design, Krippendorff's alpha was as follows. Technical design (0.208), Experience Design (0.352), Design Methods (0.397). These alpha values can be interpreted as "fair agreement" among our experts in their views on haptic application design details [49]. However, it has been recommended that an alpha value of 0.667 to 0.8 would be more ideal values for inter-rater agreement [50].

Overall Impressions - Based on this limited sample, there were hints that our experts were different in their interpretations of haptic application design.

Chapter 6

Discussion

This chapter will discuss our results regarding our focal points and associated research questions.

We will discuss the nature of differences/similarities on several aspects of haptic application design such as the types of user applications being made, the hardware used, technical and user experience details being given, and the description/perspectives from the communities.

We will also preface by outlining the limitations that should be taken into consideration when interpreting the discussion to follow. We will suggest future work to extend the foundations and address the limitations of our work.

6.1 Limitations of Our Work

There are several limitations of our work that should be taken into consideration.

We were working under a number of constraints as we prototyped a new methodology. We have a number of observations for ways our process could be improved. Having more resources (eg. bigger author team) would have also been helpful.

Our limitations and its effect on the validity of our findings are as follows:

1. **Limited Number of Venues -** We used a scoping review methodology to systematically identify a review set of papers from a large body of literature. In this first exploratory pass, we applied this methodology to a limited set of venues so that the resulting review set would fit within our limited analysis resources.

   In general, we considered our scoping review methodology a success due to our numerous filtering and paper inclusion checking steps creating a manageable set of papers for analysis. However, our final set of analyzed papers was too small to support generalizable interpretations (e.g. inferential statistics). This limited the degree to which we could form insights into how design practices varied among the communities. We emphasize that this was a factor of the size of our sample, and not the methodology of identifying appropriate samples for review.

2. **Main Author Team Bias -** Many mechanics of our scoping review relied on human driven decisions regarding search terms (keywords) and the generation of qualitative codes to characterize general community design practices.

   There was a risk of bias at play, where it was possible that another set of researchers will have come to different interpretations of which papers should be analyzed. Thus, data such as keywords or qualitative codes would have been different as a result.

   Specifically, in Stage 2 the research team manually selected keywords as an inclusion criteria by which to extract relevant papers from each venue, resulting in the 82 papers that left Stage 2. This manual selection stage had a subjective aspect to it, and as a result, it is possible that we chose papers that were based more on our personal interpretations of haptic application design concepts.

   We attempted to mitigate this bias through many team discussions that attempted to look at each mechanic of our methodology and how different types of community members may perceive them as representative of a community's perspective of haptic application design. However, this conversation can be improved by directly consulting more haptic experts from each community.

3. **Uneven and Limited Expert Representation -** We only had one expert representing the Haptics community. This was due to challenges in recruiting another Haptics expert within the timeframe of our study. Additionally, our experts had variance in their years of academic experience in researching and publishing haptic application design work.

   Given all of this, the final sample of papers used for analysis should be taken with more precaution in its characterizations of haptic application design practices. Future iterations of our work could involve a larger, diverse, and more experienced set of researchers to ensure a more equal/experienced set of eyes on viewing haptic application design literature. Having more experts could also help clarify whether personal background and bias affects how haptic application design details are interpreted from publications.

Given these notable limitations, the reader should take the following discussion as alluding rather than confirming any differences/similarities of community haptic application design practices. More work is required to generalize our findings of community haptic application design practices. We will discuss how to correct the limitations of our work in the Future Work section below.

6.2 Focal Point 1 (Design Energy Distribution)

Our results suggested that when viewing design energy from a myriad of perspectives (community level, year level, venue size level), each community seemed to prioritize similar amounts of design energy into the areas of haptic application design with a few exceptions.

On a community level, both communities appeared to provide similar levels of details in all areas of haptic application design.

On a year level, 2014 also suggested that both communities appeared to provide similar levels of details in all areas of haptic application design. By contrast in 2018, a divergence seemed to appear where the HCI community exhibited a growth in details in all areas of haptic application design.

From a venue size level perspective, among our bigger sized sample venues, it was suggested that the HCI community prioritized experience design details. The smaller sized venues suggested some differences in details being provided. The HCI community provided slightly more details in all haptic application design areas.

When taken as a whole, it is suggested by our results that the HCI community seems to prioritize slightly more experience design details, while the Haptics community seems consistent in providing good levels of design details in all areas of haptic application design. Furthermore, this maybe a recent pattern, given that in 2014 both communities seemed consistent in their level of haptic application design details among the included papers.

However, this pattern may simply be due to the way in which we presented the papers to our experts. 2014 papers were listed first, and while we did not stipulate a certain order of papers to be checked, it maybe the case that the experts used the 2014 papers to create a baseline of their rating patterns. Thus, the year level differences should be taken cautiously.

Due to our limitation of uneven group sizes in all of the comparisons, all of our design energy analysis should be taken cautiously. In particular, certain community patterns on design energies can be inflated by the differences in group size.

6.3 Focal Point 2 (Purpose of Haptics in User Experiences)

Based the main author's analysis, it was suggested that each community seemed to emphasize different types of user experiences.

The HCI community seemed to emphasize social communication, visual impairment support, and professional physical support application experiences. The Haptics community seemed to emphasize experiences for medical professionals and physical rehabilitation. Both communities shared driving support experiences.

Furthermore, it appears that the purported reasons to design with haptic technology can be corroborated with these user experiences. The HCI community seemed to use haptic technology as an information display to a greater extent than that of the Haptics community. Information displays can be a possible way in which social communication could thrive under. The Haptics community seemed to use haptic technology to support improvements in control to a bigger extent than that of the HCI community. The dexterity training involved in medical professional and physical rehabilitation seems to be a natural fit for control improvements.

However, these interpretations should be taken cautiously. By virtue of our methodology, our final sample size of papers was greatly reduced from a much larger space of literature. Thus, it is possible that different types of experiences and associated purposes exist. Ensuring a larger final sample of papers could be one way to discover whether other experiences/purposes exist.

6.4 Focal Point 3 (Design Methods Used to Create Haptic Applications)

Our results suggested that each community provided different levels of focus for different design methods.

Within technical design, the HCI community seemed to focus on providing general system implementation details. In addition to general system implementation details, the Haptics community appeared to give more specific technical design details in the form of algorithms and stimuli parameters. Interestingly, the HCI community appeared to exhibit unique instances of design sketching system behaviour (eg. prototyping different types of hardware or stimuli).

In terms of describing their design methods, the HCI community appeared to provide use-cases and possible design spaces to ratify the purpose of a haptic application to a much larger extent than the Haptics community. The Haptics community appeared report on these details to a lower extent, perhaps due to a technological contribution being obviously applicable for a certain class of user applications. It was also found that both communities did not always report design method details. Occasionally, the HCI community also seemed to exhibit a few unique instances of brainstorming, rapid prototyping, co-design and low fidelity prototyping.

Each community also appeared to have distinct preferences for certain hardware. The HCI community seemed to prefer tactile display technologies. The Haptics community seemed to prefer force feedback technologies. Interestingly, both communities were also interested in vibrotactile display technologies. The HCI community appeared to have a few unique instances of midair and dissipative technologies.

These preferences for certain hardware could be tied to each community's preferred user applications. Medical professional, physical rehabilitation and driving applications that require good control is more amenable towards force feedback technology, which can provide higher fidelity haptic effects. Meanwhile, information displays can be created using vibrotactile or tactile display technologies, which is amenable to general user application channels such as smartphones.

It is important to be cautious of these interpretations. It maybe the case that our methodology's sampling methods resulted in these particular patterns to be exhibited when other patterns were possible. Thus, it is important to examine a larger sample of papers in the future.

6.5 Focal Point 4 (Understanding Community Perspectives on Haptic Application Design)

Each community appeared to use different types of keyword classes to describe haptic application design.

This author team developed keyword classes out of the keywords that authors of the selected papers used to describe their own papers. Thus, there is some potential for subjectivity in the creation of these keyword classes. However, we see an opportunity for a larger conversation of what keyword classes should best represent the diverse perspectives of these communities. But, keeping this in mind, we found different distributions of our keyword classes in the haptic application design papers from each community.

The HCI community keyword classes appeared to involve haptic technology, and not typically words related to interaction or user experiences. This could be due to the implicit interaction aspect of the HCI community.

The Haptics community keyword classes appeared to evoke activity-based keywords, rather than words regarding haptic technology. This could be due to the implicit technological aspect of the Haptics community.

It is possible that differences in the community backgrounds, described in Chapter 2 (Background), could partially explain the differences we saw in how haptic application design was described.

It is difficult to say whether the haptic experts' rating data indicated individual patterns and biases in their ratings, given the small number of raters employed. There is no doubt that their ratings differed, but we cannot say how these might link to factors like disciplinary background and specifics of their own design experience versus the personal tendencies we might see in any kind of rating tasks (eg. a tendency to rate more harshly or generously) without larger rater numbers.

6.6 Overall Impressions - Are the Communities Different or Similar to Each Other?

Our methodology and results seemed to suggest that the HCI and Haptics communities practiced haptic application design more differently rather than similarly.

In terms of the design energy, possible differences seemed to exist in terms of the HCI community investing more detail in user experience design details. In terms of the keywords used to report haptic application design work, the communities did not appear to share much language with each other. However, this maybe due to a bias in main author keyword selection.

The most notable differences appeared to be the different types of user applications being designed, the purposes of why haptic technology was used in a design, and the technological preferences of the communities. While often both communities exhibited many shared examples in applications and technology, the differences appeared in the extent of papers reporting such details. The potential source of these differences could be due to the respective backgrounds of each community informing what type of haptic application details are important.

Some similarities were noticed. In terms of design methods being reported, each community seemed to place more value on providing technical oriented details, with the HCI community providing general system details while the Haptics community provided more specific technical implementation details. Vibrotactile technology appeared to be a popular technology that was used in almost equal degrees by both communities.

6.7 Future Work - Suggestions for Improving Our Study

We recommend the following next steps to address the limitations of our study in two key ways. The first way being to improve the methodology of the current work, and the second way suggesting how to use this work for different types of studies.

Improving Methodology of Current Work

1. **Expand the Sample Size and Groups Being Studied -** The confidence of our results can increase by expanding the number of papers and community groups. We describe a possible approach using Figure 8.1 in the Appendix section.

2. **Involve More Community Experts -** Our current study only involved 3 experts. We also did not have equal representation of the communities among our experts (2 HCI, 1 Haptics). Thus, having equal numbers of experts representing the communities can help gain more fair views on haptic application design.

Suggestions for Different Studies

1. **Investigate How Much "Cross-Fertilization" is Happening -** Our study provided a very high level look on how communities practiced haptic application design. It would be interesting to investigate how researchers with a mixed HCI and Haptics community background approaches haptic application design projects. This investigation could be started by examining whether authors of the venues used in our study have published in other community venues.

2. **Open the Discussion on the Differences/Similarities of Haptic Research Communities -** We hope that this research shed some light to the nature of design differences found between the communities. It would be interesting to see the different community members talk to each other about our findings in order to obtain ideas and opportunities for haptic application design knowledge sharing.

Chapter 7

Conclusions

Our research goal was to discover the different/similar community practices used to design haptic applications. Specifically, we wished to gain insights into design practices regarding the technical design, experience design, and design methods used to create haptic applications. We contributed a novel scoping literature review methodology to carefully find and compare haptic application design papers representative of the communities.

Our results contributed an initial characterization of haptic application design practices common among the communities. Our results indicated many areas of differences rather than similarities.

As mentioned in our introduction, our results have interesting implications for the communities in terms of opportunities for knowledge sharing. The nature of the differences was of an complementary nature, that could allow for one community's knowledge to "fill in the gaps" of another community. For example, the HCI community could leverage the excellent technical details of the Haptics community to improve the saliency of haptic information displays. The Haptics community could leverage the ideation and use-case defining approaches of the HCI community to create experiences accessible to a broader audience. Our results, while preliminary, suggest that there is potential for each community to leverage each other's strengths in order to improve or create new types of haptic application experiences.

However, these implications will need to be investigated further. The expansion of papers and different community venues can help verify the generalizability of our results. Investigating mixed community background researcher's approaches to haptic application design can detail the benefits/specifics of design knowledge cross-fertilization.

Despite the limitations and scale of this study, we believe the future is bright for the HCI and Haptics communities. We are excited by the possibilities of new meaningful haptic application experiences for when the communities are ready to collaborate with each other. The seeds of knowledge are just waiting to be shared and grown.

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Chapter 8

Appendix

8.1 Future Work - Systematically Finding Appropriate Venues

It was described in Chapter 4 (Methodology) that the main author team's personal knowledge served as the primary basis for choosing the venues of our study.

After completing this study, we believe the following approach could be used in future work to methodically pick new research venues.

Figure 8.1 details a possible approach in utilizing "yields", an estimation of a venue's number of haptic application design papers.

How to Calculate Yield - Researchers can first find the total number of papers from possible haptic application design venues. Next, an estimation of the number of haptic application design papers could be made using personal knowledge and expert advice regarding the possible venues. Lastly, the resulting yield (proportion of haptic application design papers over a venue's total paper set) can then be used as a measure to decide whether a venue is worthwhile for analysis.

Venue/Year	# Total Papers	# Haptic Application Design Papers Found	Resulting Haptic Application Paper Yield %
CHI 2014	465	7	1.51%
CHI 2018	666	14	2.10%
UIST 2018	80	3	3.75%
ToH 2014	51	6	11.76%
ToH 2018	61	7	11.48%
HS 2018	57	1	1.75%

Figure 8.1: A possible approach to find new venues for analysis. The actual number of haptic application design papers found are used for illustration.

8.2 Papers Used to Generate Focal Points

The following example papers were used to generate our focal points regarding the technical, user experience and design methods of haptic applications practiced in both communities. These papers were chosen from notable haptic research venues based on our personal knowledge. However, the year of the papers were not the same as the final years chosen in our methodology. The year span used in our methodology was intentionally different.

Venue/Year	Focal Point Generating Publication
CHI 2016	S. Kratz and A. Dunnigan, "Thermotouch: Design of a high dynamic temperature range thermal haptic display," in CHI Proc. Conf. Extended Abstracts on Human Factors in Computing Systems. ACM, 2016, pp. 1577-1582.
CHI 2016	S. Khurelbaatar et al. "Tactile presentation to the back of a smartphone with simultaneous screen operation," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2016, pp. 3717-3721.
CHI 2016	A. Tanaka and A. Parkinson, "Haptic wave: A cross-modal interface for visually impaired audio producers," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2016, pp. 2150-2161.
CHI 2016	M. Ernst and A. Girouard, "Exploring haptics for learning bend gestures for the blind," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2016, pp. 2097-2104.
CHI 2016	J. Nishida and K. Suzuki, "Biosync: Synchronous kinesthetic experience among people," in CHI Proc. Conf. Extended Abstracts on Human Factors in Computing Systems. ACM, 2016, pp. 3742-3745.
CHI 2016	R. Ueoka, M. Yamaguchi, and Y. Sato, "Interactive Cheek Haptic Display with Air Vortex Rings for Stress Modification," in CHI Proc. Conf. Extended Abstracts on Human Factors in Computing Systems. ACM, 2016, pp. 1766-1771.
CHI 2016	A. Gupta et al. "Direct manipulation in tactile displays," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2016, pp. 3683-3693.
UIST 2016	J. Ou et al. "aeroMorph-heat-sealing inflatable shape-change materials for interaction design," in UIST Proc. 29th Annual Symp. on User Interface Software and Technology. ACM, 2016, pp. 121-132.
UIST 2016	Y. Cho et al. "RealPen: Providing realism in handwriting tasks on touch surfaces using auditory-tactile feedback," in UIST Proc. 29th Annual Symp.on User Interface Software and Technology. ACM, 2016, pp. 195-205.
UIST 2016	J. Gugenheimer et al. "Gyrovr: Simulating inertia in virtual reality using head worn flywheels," in UIST Proc. 29th Annual Symp. on User Interface Software and Technology. ACM, 2016, pp. 227-232.
UIST 2016	P. Lopes et al. "Muscle-plotter: An interactive system based on electrical muscle stimulation that produces spatial output," in UIST Proc. 29th Annual Symp. on User Interface Software and Technology. ACM, 2016, pp. 207-217.
UIST 2016	A. Dementyev et al. "Rovables: Miniature on-body robots as mobile wearables," in UIST Proc. 29th Annual Symp. on User Interface Software and Technology. ACM, 2016, pp. 111-120.

Table 8.1: HCI community example papers used to inspire our focal points.

Venue/Year	Focal Point Generating Publication
HS 2016	D. Spelmezan et al. "SkinHaptics: Ultrasound focused in the hand creates tactile sensations," in HAPTICS Haptics Symp. IEEE, 2016, pp. 98-105.
HS 2016	M. Gabardi et al. "A new wearable fingertip haptic interface for the rendering of virtual shapes and surface features," in HAPTICS Haptics Symp. IEEE, 2016, pp. 140-146.
HS 2016	A. Russomanno et al. "Modeling latching fluidic circuits to determine clocking limits for a refreshable braille display," in HAPTICS Haptics Symp. IEEE, 2016, pp. 179-184.
HS 2016	M. Price and F.C. Sup, "A robotic touchscreen totem for two-dimensional haptic force display," in HAPTICS Haptics Symp. IEEE, 2016, pp. 72-77.
HS 2016	A.J. Spiers and A.M. Dollar, "Outdoor pedestrian navigation assistance with a shape-changing haptic interface and comparison with a vibrotactile device," in HAPTICS Haptics Symp. IEEE, 2016, pp. 34-40.
HS 2016	J.H. Bae et al. "Display of needle tip contact forces for steering guidance," in HAPTICS Haptics Symp. IEEE, 2016, pp. 332-337.
ToH 2016	F. Dimeas and N. Aspragathos, "Online stability in human-robot cooperation with admittance control," IEEE Trans. on Haptics, vol.9, no.2, pp. 267-278, 2016.
ToH 2016	S. Yim, S. Jeon and S. Choi, "Data-driven haptic modeling and rendering of viscoelastic and frictional responses of deformable objects," IEEE Trans. on Haptics, vol.9, no.4, pp. 548-559, 2016.
ToH 2016	P. Olsson et al. "Comparison of walking and traveling-wave piezoelectric motors as actuators in kinesthetic haptic devices," IEEE Trans. on Haptics, vol.9, no.3, pp. 427-431, 2016.
ToH 2016	V. Girbes et al. "Haptic feedback to assist bus drivers for pedestrian safety at low speed," IEEE Trans. on Haptics, vol.9, no.3, pp. 345-357, 2016.
ToH 2016	S. Okamoto, M. Wiertlewski and V. Hayward, "Anticipatory vibrotactile cueing facilitates grip force adjustment during perturbative loading," IEEE Trans. on Haptics, vol.9, no.2, pp. 233-242, 2016.
ToH 2016	J. Lee, Y. Kim and G.J. Kim, "Rich pinch: Perception of object movement with tactile illusion," IEEE Trans. on Haptics, vol.9, no.1, pp. 80-89, 2016.

Table 8.2: Haptics community example papers used to inspire our focal points.

8.3 Papers Used in Methodology and Analysis

Our scoping review involved many stages filtering out papers from a large research space. This was in order to find the most suitable papers appropriate for analysis. Please refer to Chapter 4 (Methodology) for specific details.

Stage 2 of our methodology established a possible set of 82 haptic application design papers inferred from analyzing the keyword metadata of our venue's papers. This came from the rejection of 1298 papers from the original number of papers provided by each of our venues.

While Stage 2 used a mixed automatic and human decision approach to filter out papers. The subsequent stages involved much more human interpretations and judgements that warrants examples that illustrates what sort of papers tended to be dropped from our study.

Stage 3 of our methodology involved the first author reading the titles/abstracts of Stage 2's 82 papers in order to make a judgement for further inclusion in the study. Table 8.3 shows the 22 dropped papers that were considered not appropriate for study inclusion. These papers involved the HCI community exclusively. After the 22 papers were dropped, 60 papers remained possible candidates for further analysis.

Venue/Year	Excluded Publication
CHI 2014	L.P. Cheng et al. "Haptic turk: a motion platform based on people," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 3463-3472.
CHI 2018	H. Kim et al. "Hapcube: A wearable tactile device to provide tangential and normal pseudo-force feedback on a fingertip," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-13.
CHI 2018	A. Niijima et al. "Controlling maximal voluntary contraction of the upper limb muscles by facial electrical stimulation," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-7.
CHI 2018	K. Kato et al. "Double-sided printed tactile display with electro stimuli and electrostatic forces and its assessment," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-12.
CHI 2018	I.Choi et al. "Claw: A multifunctional handheld haptic controller for grasping, touching, and triggering in virtual reality," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-13.
CHI 2018	A. Delazio et al. "Force jacket: Pneumatically-actuated jacket for embodied haptic experiences," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-12.
CHI 2018	S. Heo et al. "Thor's hammer: An ungrounded force feedback device utilizing propeller-induced propulsive force," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-11.
CHI 2018	E. Strasnick et al. "Haptic links: Bimanual haptics for virtual reality using variable stiffness actuation, " in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-12.
CHI 2018	G. Park and S. Choi, "Tactile information transmission by 2d stationary phantom sensations," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-12.
CHI 2018	P. Abtahi and S. Follmer, "Visuo-haptic illusions for improving the perceived performance of shape displays," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-13.
CHI 2018	Y.A. Shim, J. Lee and G. Lee, "Exploring multimodal watch-back tactile display using wind and vibration," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-12.
CHI 2018	G. Wang et al. "Printed paper actuator: A low-cost reversible actuation and sensing method for shape changing interfaces," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-12.
CHI 2018	E. Whitmire et al. "Haptic revolver: Touch, shear, texture, and shape rendering on a reconfigurable virtual reality controller," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-12.
CHI 2018	D.R. Sahoo et al. "Tangible drops: a visio-tactile display using actuated liquid-metal droplets," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 1-14.
UIST 2018	A. Withana, D. Groeger and J. Steimle, "Tacttoo: A thin and feel-through tattoo for on-skin tactile output," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 365-378.
UIST 2018	J.Y. Lo et al. "RollingStone: Using Single Slip Taxel for Enhancing Active Finger Exploration with a Virtual Reality Controller," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 839-851.
UIST 2018	D.Y. Huang et al. "Orecchio: Extending body-language through actuated static and dynamic auricular postures," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 697-710.
UIST 2018	H.Y. Chang et al. "Facepush: Introducing normal force on face with head-mounted displays," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 927-935.
UIST 2018	T. Han et al. "HydRoring: Supporting mixed reality haptics using liquid flow," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 913-925.
UIST 2018	R Hinchet et al. "Dextres: Wearable haptic feedback for grasping in vr via a thin form-factor electrostatic brake," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 901-912.
UIST 2018	B. Son and J. Park, "Haptic feedback to the palm and fingers for improved tactile perception of large objects," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 757-763.
UIST 2018	G. Wang et al. "4DMesh: 4D printing morphing non-developable mesh surfaces," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 623-635.

Table 8.3: The 22 excluded papers based on title/abstract checking by the first author.

Stage 3 also involved different haptic experts reading the 60 papers produced by title/abstract checking. Table 8.4 and Table 8.5 shows the 14 dropped papers across the HCI and Haptics communities that were not considered appropriate for study inclusion by the experts. After experts checked the papers, 46 papers were considered suitable for final analysis.

Venue/Year	Excluded Publication
CHI 2014	H. Nakanishi, K. Tanaka and Y. Wada, "Remote handshaking: touch enhances video-mediated social telepresence," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 2143-2152.
CHI 2014	J. Kangas et al. "Gaze gestures and haptic feedback in mobile devices," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 435-438.
CHI 2014	P. Dimitriadis and J. Alexander, "Evaluating the effectiveness of physical shape-change for in-pocket mobile device notifications," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 2589-2592.
UIST 2018	M. Ogata, "Magneto-Haptics: Embedding Magnetic Force Feedback for Physical Interactions," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 737-743.

Table 8.4: The 4 HCI papers deemed not suitable for further analysis by our experts. This shows 4 out of 14 papers deemed not suitable for further analysis.

Venue/Year	Excluded Publication
ToH 2014	C. Ho, R. Gray and C. Spence, "Reorienting driver attention with dynamic tactile cues," IEEE Trans. on Haptics, vol.7, no.1, pp. 86-94, 2014.
ToH 2014	F. Mars, M. Deroo and J.M. Hoc, "Analysis of human-machine cooperation when driving with different degrees of haptic shared control," IEEE Trans. on Haptics, vol.7, no.3, pp. 324-333, 2014.
ToH 2014	F. Vérité, W. Bachta and G. Morel, "Closed loop kinesthetic feedback for postural control rehabilitation," IEEE Trans. on Haptics, vol.7, no.2, pp. 150-160, 2014.
ToH 2014	L. Corenthy et al. "Haptically assisted connection procedure for the reconstruction of dendritic spines," IEEE Trans. on Haptics, vol.7, no.4, pp. 486-498, 2014.
ToH 2014	S. Scheggi, F. Morbidi and D. Prattichizzo, "Human-robot formation control via visual and vibrotactile haptic feedback," IEEE Trans. on Haptics, vol.7, no.4, pp. 499-511, 2014.
ToH 2014	D. Wang et al. "Haptic simulation of organ deformation and hybrid contacts in dental operations," IEEE Trans. on Haptics, vol.7, no.1, pp. 48-60, 2014.
HS 2018	J. Anlauff, T. Kim, and J.R. Cooperstock, "Feel-a-bump: Haptic feedback for foot-based angular menu selection," in HAPTICS Haptics Symp. IEEE, 2018, pp. 175-179.
HS 2018	S.M. Sketch, A.J. Bastian and A.M. Okamura, "Comparing proprioceptive acuity in the arm between joint space and task space," in HAPTICS Haptics Symp. IEEE, 2018, pp. 125-132.
HS 2018	D.C. Egloff, M.M. Wanderley and I. Frissen, "Haptic display of melodic intervals for musical applications," in HAPTICS Haptics Symp. IEEE, 2018, pp. 284-289.
HS 2018	H. Culbertson et al. "A social haptic device to create continuous lateral motion using sequential normal indentation," in HAPTICS Haptics Symp. IEEE, 2018, pp. 32-39.

Table 8.5: The 10 Haptics papers deemed not suitable for further analysis by our experts. This shows 10 out of 14 papers deemed not suitable for further analysis.

Before analysis of the 46 expert checked papers was fully conducted, the first author conducted a final paper suitability check. From this check, 8 papers were dropped. Table 8.6 and Table 8.7 shows the 8 dropped papers across the HCI and Haptics communities that were not considered appropriate for final analysis by the first author.

Venue/Year	Excluded Publication
UIST 2018	S.Y. Teng et al. "Pupop: Pop-up prop on palm for virtual reality," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 5-17.

Table 8.6: The single HCI paper deemed not suitable for final analysis by the first author. This shows 1 out of 8 papers deemed not suitable for final analysis.

Venue/Year	Excluded Publication
ToH 2014	S. Jeon and M. Harders, "Haptic tumor augmentation: Exploring multi-point interaction," IEEE Trans. on Haptics, vol.7, no.4, pp. 477-485, 2014.
ToH 2014	F. Gonzalez, F. Gosselin and W. Bachta, "Analysis of hand contact areas and interaction capabilities during manipulation and exploration," IEEE Trans. on Haptics, vol.7, no.4, pp. 415-429, 2014.
ToH 2014	C.K. Williams and H. Carnahan, "Motor learning perspectives on haptic training for the upper extremities," IEEE Trans. on Haptics, vol.7, no.2, pp. 240-250, 2014.
ToH 2014	M. Azadi and L.A. Jones, "Evaluating vibrotactile dimensions for the design of tactons," IEEE Trans. on Haptics, vol.7, no.1, pp. 14-23, 2014.
ToH 2014	N. Garcia-Hernandez et al. "How tactor size and density of normal indentation tactile displays affects grating discrimination tasks," IEEE Trans. on Haptics, vol.7, no.3, pp. 356-366, 2014.
ToH 2018	M. Ogrinc et al. "Sensory integration of apparent motion speed and vibration magnitude," IEEE Trans. on Haptics, vol.11, no.3, pp. 455-463, 2018.
HS 2018	J. Jiao et al. "Data-driven rendering of fabric textures on electrostatic tactile displays," in HAPTICS Haptics Symp. IEEE, 2018, pp. 169-174.

Table 8.7: The 7 Haptics papers deemed not suitable for final analysis by the first author. This shows 7 out of 8 papers deemed not suitable for final analysis.

We used the following 38 papers in our final analysis described in Chapter 4 (Methodology). Table 8.8 shows the final HCI community papers. Table 8.9 shows the final Haptics community papers.

Venue/Year	Analyzed Publication
CHI 2014	T. Hachisu and M. Fukumoto, "VacuumTouch: attractive force feedback interface for haptic interactive surface using air suction," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 411-420.
CHI 2014	E. Gronvall et al. "Causing commotion with a shape-changing bench: experiencing shape-changing interfaces in use," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 2559-2568.
CHI 2014	M. Prasad et al. "Haptimoto: Turn-by-turn haptic route guidance interface for motorcyclists," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 3597-3606.
CHI 2014	G. Wilson et al. "Perception of ultrasonic haptic feedback on the hand: localisation and apparent motion," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 1133-1142.
CHI 2014	J. Park et al. "Wrigglo: shape-changing peripheral for interpersonal mobile communication," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 3973-3976.
CHI 2014	J. Mullenbach et al. "Exploring affective communication through variable-friction surface haptics," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 3963-3972.
CHI 2014	I. Politis, S.A. Brewster and F. Pollick, "Evaluating multimodal driver displays under varying situational urgency," in SIGCHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2014, pp. 4067-4076.
CHI 2018	A. Van Oosterhout, M. Bruns Alonso and S. Jumisko-Pyykko, "Ripple thermostat: Affecting the emotional experience through interactive force feedback and shape change," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 655.
CHI 2018	A.F. Siu et al. "Shapeshift: 2D spatial manipulation and self-actuation of tabletop shape displays for tangible and haptic interaction," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 291.
CHI 2018	P. Lopes et al. "Adding force feedback to mixed reality experiences and games using electrical muscle stimulation," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 446.
CHI 2018	H. Gil et al. "Whiskers: Exploring the Use of Ultrasonic Haptic Cues on the Face," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 658.
CHI 2018	J Gong et al. "Jetto: Using lateral force feedback for smartwatch interactions," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 426.
CHI 2018	P. Strohmeier, S. Boring and K. Hornbæk, "From pulse trains to coloring with vibrations: Motion mappings for mid-air haptic textures," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 65.
CHI 2018	S. Zhao et al. "Coding tactile symbols for phonemic communication," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 392.
CHI 2018	J. Bornschein, D. Bornschein and G. Weber, "Comparing computer-based drawing methods for blind people with real-time tactile feedback," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 115.
CHI 2018	Y. Zhao et al. "Enabling People with Visual Impairments to Navigate Virtual Reality with a Haptic and Auditory Cane Simulation," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 116.
CHI 2018	S. Je et al. "PokeRing: Notifications by Poking Around the Finger," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 542.
CHI 2018	H. Kim, C. Coutrix and A. Roudaut, "KnobSlider: Design of a Shape-Changing UI for Parameter Control," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 339.
CHI 2018	F. Kiss et al. "Navigation systems for motorcyclists: exploring wearable tactile feedback for route guidance in the real world," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 617.
CHI 2018	T. Komatsu et al. "Vibrational Artificial Subtle Expressions: Conveying System's Confidence Level to Users by Means of Smartphone Vibration," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 478.
CHI 2018	J. Seo. et al. "Substituting Motion Effects with Vibrotactile Effects for 4D Experiences," in CHI Proc. Conf. on Human Factors in Computing Systems. ACM, 2018, pp. 428.
UIST 2018	O. Schneider et al. "DualPanto: A Haptic Device that Enables Blind Users to Continuously Interact with Virtual Worlds," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 877-887.
UIST 2018	H. Pohl and K. Hornbæk, "ElectricItch: Skin Irritation as a Feedback Modality," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 765-778.
UIST 2018	M. Teyssier et al. "MobiLimb: Augmenting Mobile Devices with a Robotic Limb," in UIST Proc. 31st Annual Symp. on User Interface Software and Technology. ACM, 2018, pp. 53-63.

Table 8.8: The final included 24 HCI community papers used in our analysis.This represents 24 out of 38 papers used for the final analysis.

Venue/Year	Analyzed Publication
ToH 2014	M. Hirokawa et al. "Effect of haptic assistance on learning vehicle reverse parking skills," IEEE Trans. on Haptics, vol.7, no.3, pp. 334-344, 2014.
ToH 2014	X. Chen et al. "Design of a robotic mobility system with a modular haptic feedback approach to promote socialization in children," IEEE Trans. on Haptics, vol.7, no.2, pp. 131-139, 2014.
ToH 2014	J.C. Metzger et al. "Neurocognitive robot-assisted therapy of hand function," IEEE Trans. on Haptics, vol.7, no.2, pp. 140-149, 2014.
ToH 2014	A. Theriault, M. Nagurka and M.J. Johnson, "Design and development of an affordable haptic robot with force-feedback and compliant actuation to improve therapy for patients with severe hemiparesis," IEEE Trans. on Haptics, vol.7, no.2, pp. 161-174, 2014.
ToH 2014	A. Ajoudani et al. "Exploring teleimpedance and tactile feedback for intuitive control of the pisa/iit softhand," IEEE Trans. on Haptics, vol.7, no.2, pp. 203-215, 2014.
ToH 2014	C. Pacchierotti et al. "Teleoperation of steerable flexible needles by combining kinesthetic and vibratory feedback," IEEE Trans. on Haptics, vol.7, no.4, pp. 551-556, 2014.
ToH 2018	E. Olivieri et al. "Haptic feedback for control and active constraints in contactless laser surgery: concept, implementation, and evaluation," IEEE Trans. on Haptics, vol.11, no.2, pp. 241-254, 2018.
ToH 2018	G. Korres et al. "A vibrotactile alarm system for pleasant awakening," IEEE Trans. on Haptics, vol.11, no.3, pp. 357-366, 2018.
ToH 2018	G. Liu et al. "Effect of electrostatic tactile feedback on accuracy and efficiency of pan gestures on touch screens," IEEE Trans. on Haptics, vol.11, no.1, pp. 51-60, 2018.
ToH 2018	T. Fukuda et al. "A pneumatic tactile ring for instantaneous sensory feedback in laparoscopic tumor localization," IEEE Trans. on Haptics, vol.11, no.4, pp. 485-497, 2018.
ToH 2018	A.K. Han et al. "MR-compatible haptic display of membrane puncture in robot-assisted needle procedures," IEEE Trans. on Haptics, vol.11, no.3, pp. 443-454, 2018.
ToH 2018	Y. Gaffary et al. "Toward Haptic Communication: Tactile Alphabets Based on Fingertip Skin Stretch," IEEE Trans. on Haptics, vol.11, no.4, pp. 636-645, 2018.
ToH 2018	A. Teranishi et al. "Combining Full and Partial Haptic Guidance Improves Handwriting Skills Development," IEEE Trans. on Haptics, vol.11, no.4, pp. 509-517, 2018.
HS 2018	W.H. Jantscher et al. "Toward improved surgical training: Delivering smoothness feedback using haptic cues," in HAPTICS Haptics Symp. IEEE, 2018, pp. 241-246.

Table 8.9: The final included 14 Haptics community papers used in our analysis. This represents 14 out of 38 papers used for the final analysis.

8.4 Expert Ratings of Included and Excluded Papers

As mentioned in the Chapter 5 Focal Point 1 Results, we also visualized the expert ratings of the distributions of included and excluded papers. This was to help show what details pushed a community's set of papers into being considered for haptic application design analysis.

Each of the figures below will show these visualizations based on the different research questions associated with Focal Point 1. Different perspectives of the expert ratings will be shown (By Community, By Year, By Venue Size). Please note that there are some differences in the visual language of the figures. Notably, compared with the figures in Chapter 5 Focal Point 1 results, the following figures utilize side-by-side barcharts that showcases how both communities fared in terms of details given for a specific area of haptic application design. Additionally, the sample information is not as detailed as the Chapter 5 figures, but they are based on the same information presented in the Chapter 5 figures.

Figure 8.2 represents how the communities behaved differently/similarly in haptic application design. The figure grouped all HCI venues against all Haptics venues used in our study.

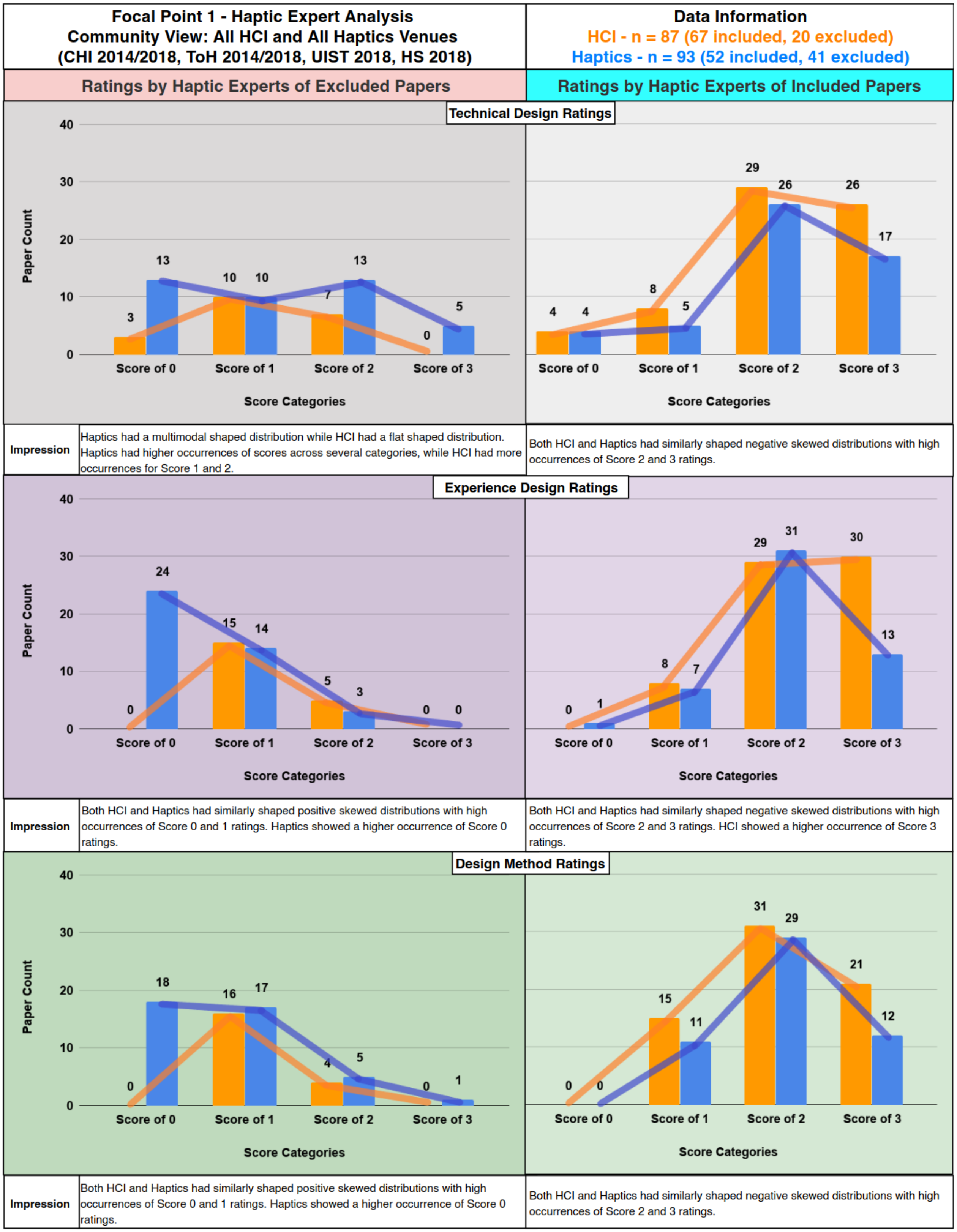

Figure 8.2: Haptic expert ratings of each community's venues on different areas of haptic application design.

Figure 8.3 represents a baseline view (2014) in which future venues can be used to detect any changes in haptic application design patterns. Figure 8.4 represents the current view (2018) of community approaches to haptic application design. This view can be compared against the 2014 view in Figure 8.3 to denote any changes in design patterns.

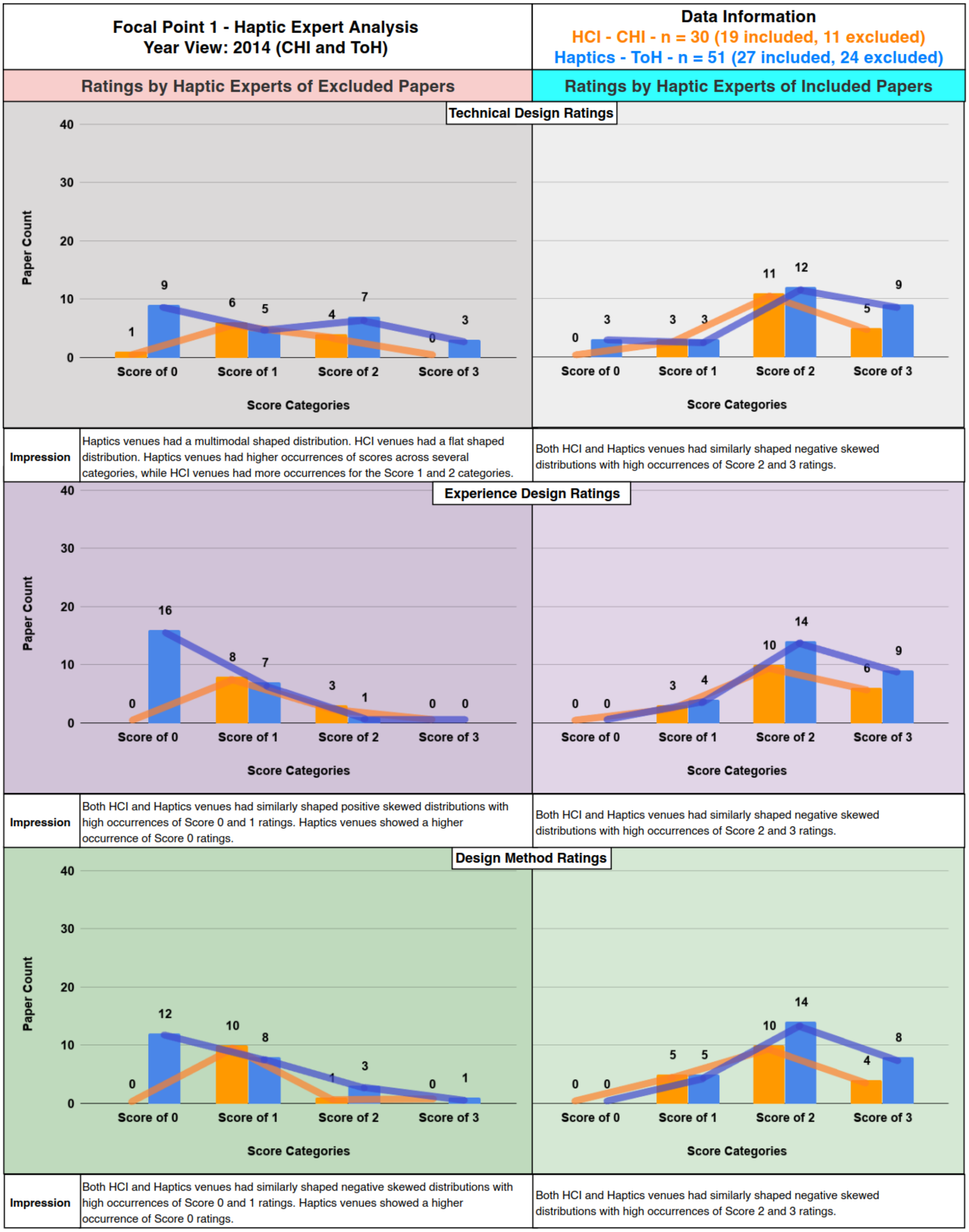

Figure 8.3: Haptic expert ratings of the 2014 community venues on different areas of haptic application design.

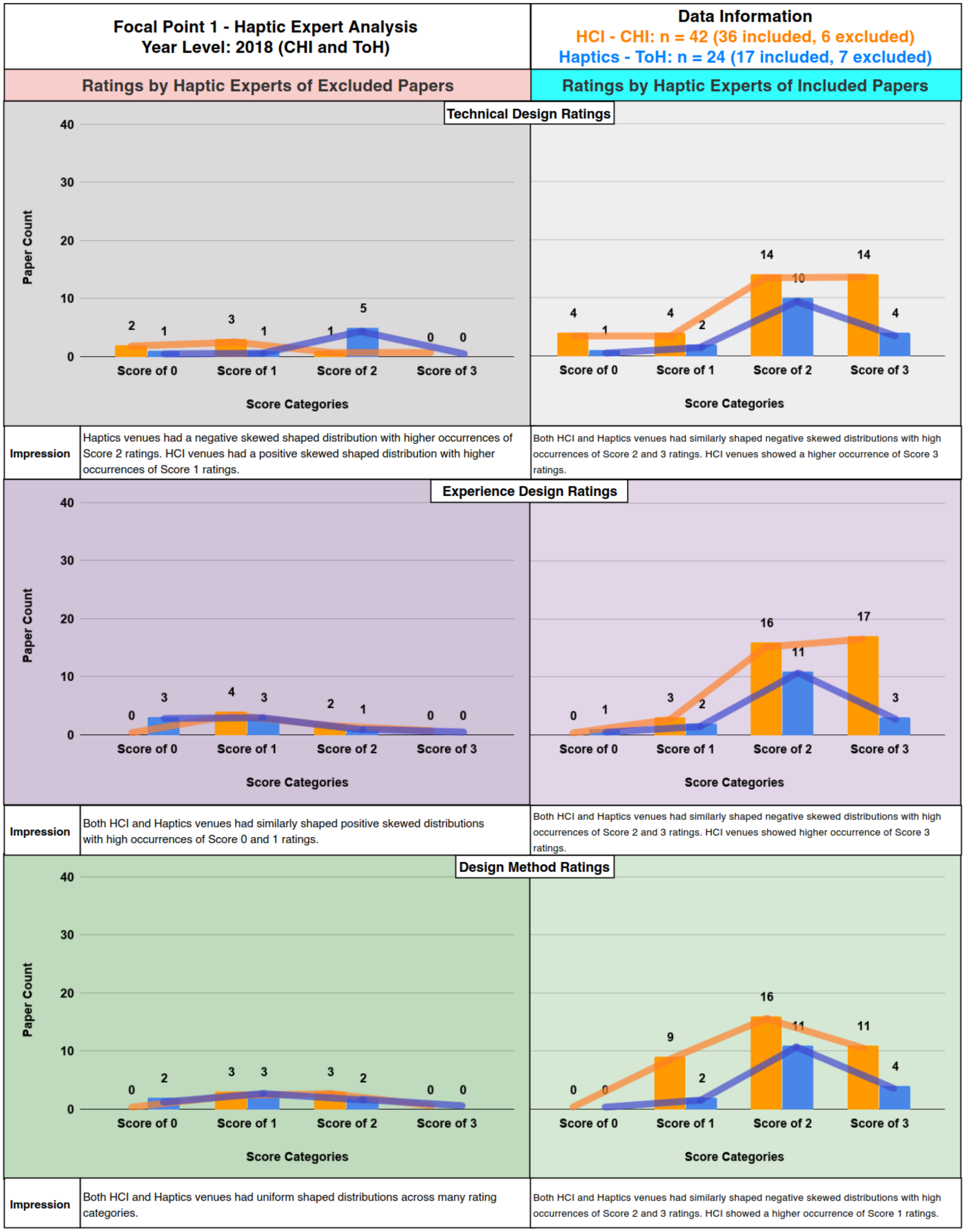

Figure 8.4: Haptic expert ratings of the 2018 community venues on different areas of haptic application design.

Figure 8.5 represents the community design patterns of the bigger sized venues (based on sample size). This view can be compared against the smaller sized venues in order to denote any differences/similarities in design patterns. Figure 8.6 represents the community design patterns of the smaller sized venues (based on sample size). This view can be compared against the bigger sized venues to denote any differences/similarities in design patterns.

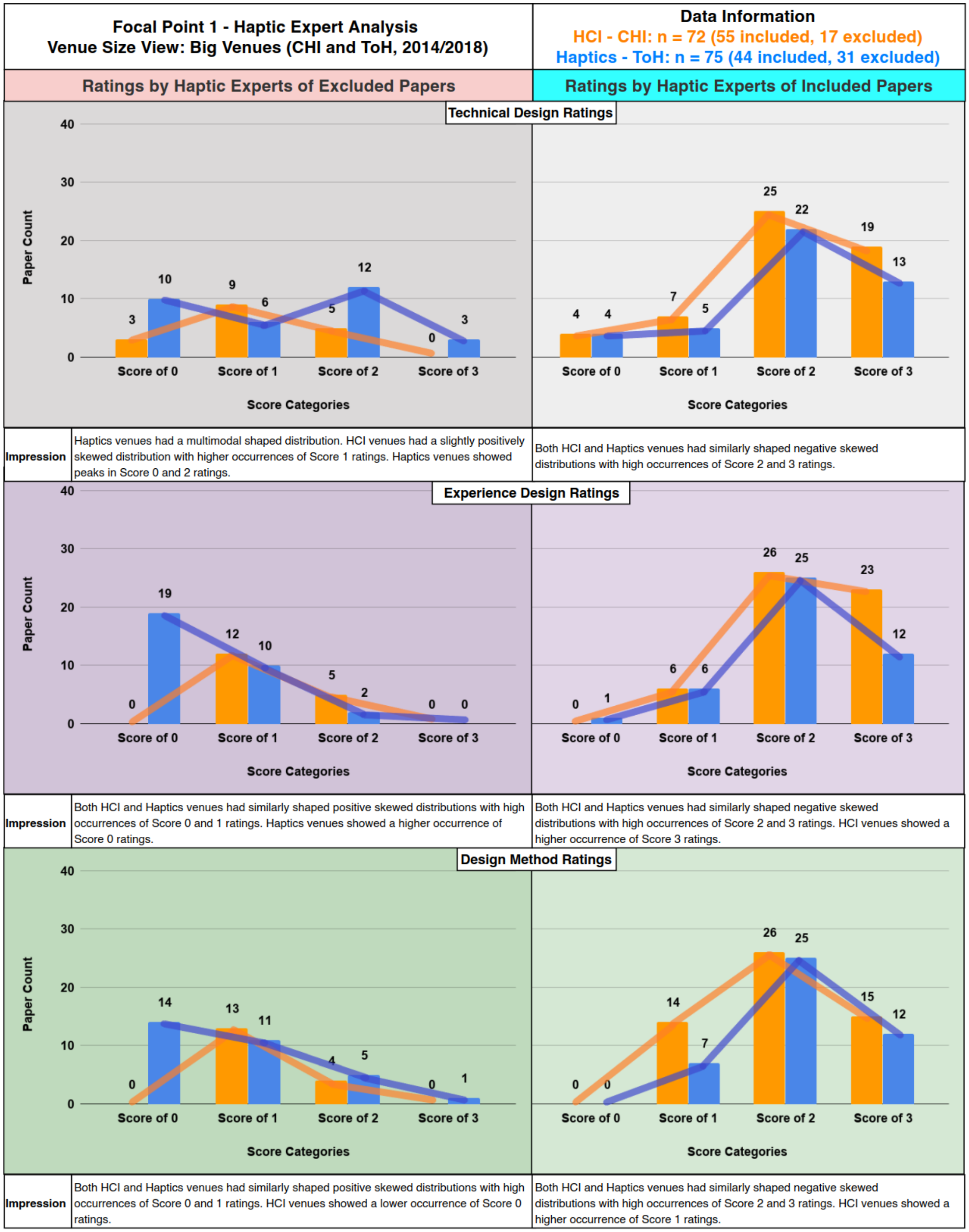

Figure 8.5: Haptic expert ratings of the bigger sample community venues on different areas of haptic application design.

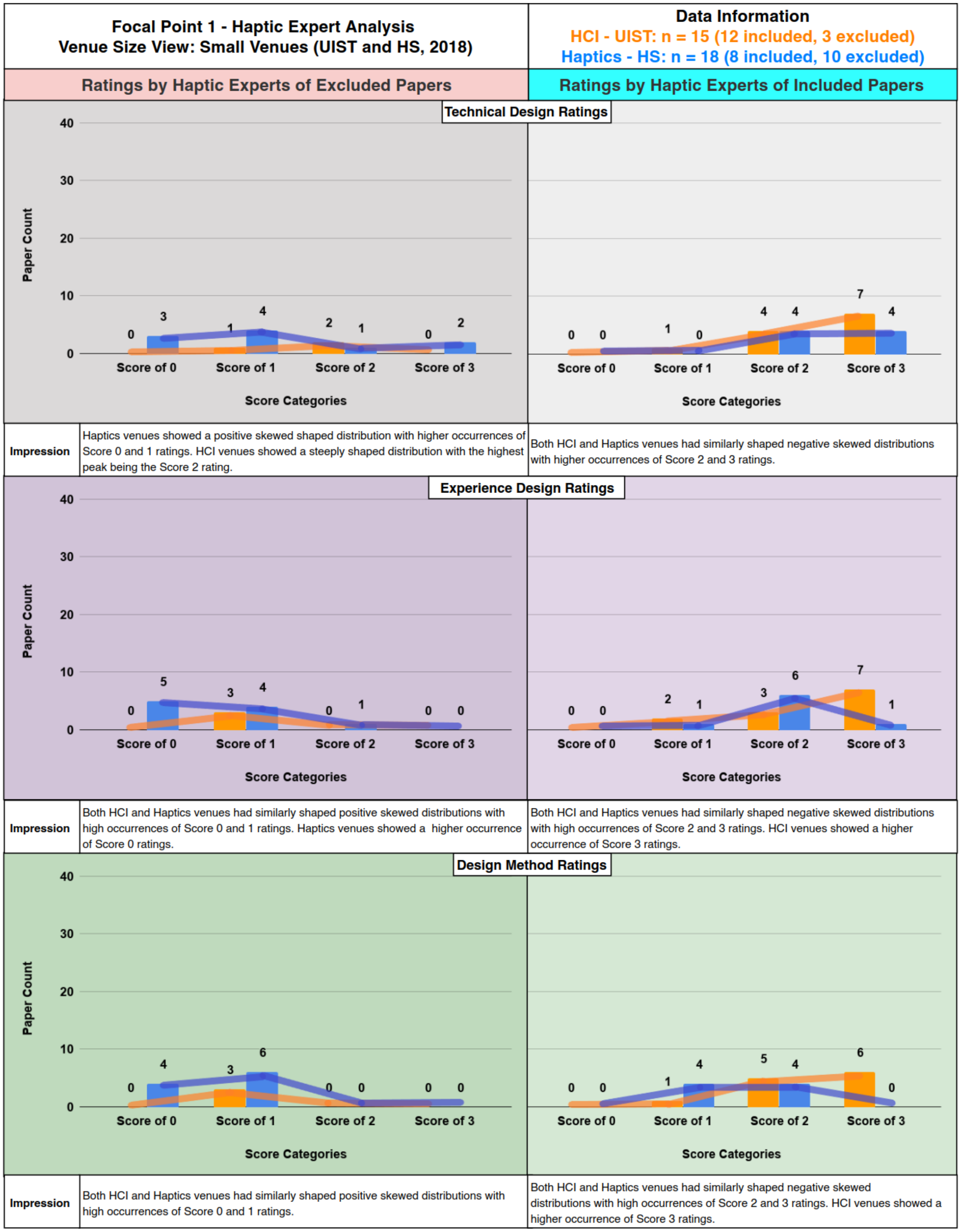

Figure 8.6: Haptic expert ratings of the smaller sample community venues on different areas of haptic application design.