Towards Ecological and Embodied Design of Auditory Display

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ABSTRACT

Auditory display research has been criticised over a perceived lack of progress in tackling key issues relating to usability and user-experience. However, emerging trends in design-thinking present new tools for addressing the usability concerns that have long beleaguered this field of inquiry. In this paper, we provide an in-depth analysis on the emergence of design-based approaches in auditory display research by mapping out the progression of current research in the field. Through an ecological and embodied approach to perception and cognition, we then evaluate user-centric design strategies as tools for better understanding complex design spaces and improving usability. We then present a discussion to elucidate the benefits to auditory display research of employing user-centric design strategies for future projects.

1. INTRODUCTION

Data has become a valuable asset and driving force in many aspects of our daily lives. The reliance of our global society on connected devices, data and information has spearheaded rapid development in many sectors of industry and society, bringing both radical innovation, as well as disruption from new and complex problems. Technologies like auditory interfaces have presented innovative opportunities for assisting the analysis and practical use of the vast range of data types that are now possible to collect. However, despite all their promise in a number of applications, auditory displays still face several key hurdles that have stifled their path towards ubiquity in our everyday environments [1].

The field of Auditory Display (AD) has long struggled to overcome key issues relating to user-experience [2]. This has been well documented by an ever growing list of publications concerned with the discussion of aesthetics and usability in AD research [3]. In response, it has been suggested that the prevalence of cognitivist and information-processing approaches in AD has led to applications that are limited in scope and ignore critical issues in design such as the aesthetic, environmental and emotional sensibilities of end-users. In turn, this has led to poor usability from designs that may work in controlled settings, but do not translate well to real world environments [4], [5].

Despite the importance of aesthetics and usability in AD [6], many challenges remain unaddressed before auditory interfaces become viable everyday technologies. Critics have noted that overall, AD research appears perpetually mired, attempting to evaluate the pros and cons between cognitivist/scientific frameworks over more human-oriented/artistic approaches to sonification [2]. This has arguably produced stagnation in the development of innovative ideas and arguments in the field [4], as researchers struggle to reconcile the different perspectives that arise from different schools of thought. Furthermore, due to the interdisciplinary nature of auditory display the prospect of developing an all-encompassing set of guidelines that are applicable to all possible contexts of auditory display applications is unrealistic [7].

To address these aesthetic and usability concerns in auditory display design, recent research has turned its focus towards user-centric design approaches [8] more commonly associated with Human-Computer Interaction and Design Research [9]. These recent developments have the potential of providing researchers with better tools for informing design, by enabling better understanding of users' environments and experiences [10].

2. BACKGROUND

2.1. Aesthetics and Usability

Auditory displays have their origin in scientific and engineering disciplines such as, computing, medicine and aviation [4]. Early AD research consisted mostly of experiments exploring sound as a medium for codifying and communicating information for utilitarian purposes (i.e. medical applications, sonar, etc.). The results of these early experiments and applications in AD are characterized by very functional sonifications of little or poor aesthetic quality (for example, the Geiger counter). These sound signals, albeit informative and appropriate within their given context, are monotonous and induce display fatigue over long periods of exposure [11].

However, as the concepts of sonification and AD have become more widely known in other fields, experimentation with these data analysis techniques outside traditional scientific disciplines has flourished. This particularly the case with the sonic arts. Sonic artists and sound designers began experimenting very early on with data driven audio for producing innovative artistic works [4]. Data driven sonic art presented an opportunity to affect and captivate listeners by presenting novel, tangible and engaging experiences of data [12]. This experimentation, alongside a desire to improve the poor user-experience in early sonification applications, brought about the consideration of aesthetics and interdisciplinarity to the forefront of the discussion on auditory interfaces, as seen at the 2002 edition of the ICAD conference [6].

The interest in AD by disciplines grounded in the arts and humanities, gave rise to tensions within this historically scientific field, where practitioners have struggled to value or incorporate the contributions of aesthetic approaches to AD research [13]. The dichotomous discussion of science vs. aesthetics in AD has been the dominating approach, mainly centred around the ambiguity introduced to data streams when codified using a heavily aesthetic approach. In contrast, the more functional and unambiguous signals produced for scientific-oriented sonifications, have been valued due to a preference in the field for quantifiable unambiguous data [1]. With the emergence of this discussion, some insights into the role aesthetics plays in the user-experience of auditory displays has been gained. However, Barrass and Vickers [4] argued that this also presented a barrier slowing progression the field by preventing the true interdisciplinary collaboration which is needed for addressing the critical issues of usability and user-experience in AD design. Despite this stagnation, it is clear the important role aesthetics play in the design of a successful auditory interface, from how it impacts the communication of the codified data, to the overall experience of the user. But what are 'good' AD designs? Or appropriate aesthetics? And how does a designer achieve usability?

Over time, considerable effort has gone into classifying different strategies in AD into categories and techniques, such as: audification, parameter-based, and model-based sonification, with the aim of converging and standardizing knowledge in the filed [14]. However, a similar classification of design strategies and techniques is not possible to standardize due to the ambiguous and complex nature of this paradigm, and therefore AD designers continue to face a great challenge when choosing a sound palette suitable for the particular data set they wish to sonify. It thus becomes clear that sound selection in AD is a complicated process dependent on the contextual and cultural aspects of listening that influence the perception and engagement of a user with sound [8].

To address the challenge of producing auditory displays that tackle the issues of usability highlighted above, it has become necessary to adopt approaches that place greater emphasis on the user and their experience. Consequently, there has been a rise in 'design-thinking' approaches, which have been suggested as possible means for improving usability and user experience in technology design [15]. These approaches break away from the polarising and hierarchical dichotomy of scientific versus artistic representation and instead frame AD design as a dynamic and adaptive interdisciplinary exercise, requiring active engagement with end-users on a more human and ecological level [16]. In the following sections we describe the development of design thinking as a practice and elucidate why it is of interest to recent AD research trends.

2.2. Design Thinking, User-centred Design and Human-Computer Interaction

The idea of 'design thinking' can be understood as the careful consideration and application of cognitive processes that culminate in design action [17]. These cognitive processes arise and are inspired from the direct observation and collaboration with end-users using ethnographic tools, with the goal of understanding the user's context and by

consequence the intended design space in its natural state [18].

Historically, the conceptualization of design thinking developed through four distinct phases, where the focus of the cognitive processes involved in design varied radically [19]. The first phase, covering the periods before 1960, conceived of the designer as an artist involved in an intuitive process. As such, design was traditionally viewed as a step in the latter stages of the product development process, whereby a designer's role would be limited to the enhancement of the aesthetics of an already developed product, and did not include providing input during the innovation/ideation stages of development [18].

The second phase of development (1960s-1980s) characterized the designer in a more cognitivist light, as a rational and logical agent involved in planning and analysis of scientific rigor [20]. Here, designers aimed at controlling or minimizing the irrational, fuzzy and abstract aspects of design and viewed design as a 'problem solving' process dissectible through the rationality of an information-processing mind.

During the third phase of development (1970s-1980s) it was realized that for pure rationality to exist, a designer must have the impossible quality of being able to attain all existing information regarding a particular design problem. As such, certain human actions that endure any level of uncertainty cannot be explained by a rationalist approach and thus the term bounded-rationality was conceived as a midpoint between pure determinism and pure rationality [21]. In this state, similarly to the second phase, the designer applies logic and rationality, albeit in a more dynamic way, to different problems as they arise and without full knowledge of all information beforehand.

The final paradigm shift towards design thinking occurred during the 1980s when the designer's role was recast to that of the reflective practitioner. This post-rationalist characterization aimed at placing the designer in a more natural state of 'reflection-in-action', whereby a designer is no longer solely dependent on preconceived knowledge or theory and technique, but instead embraces uncertainty and reflects on the situation at hand using experience and dialogue to construct a new theory for that unique case [22]. During this last stage of development, design thinking rejected the information-processing view of the 'problem-solution' framework to design, and instead embraced the concept of 'design situation' or 'design space', welcoming the consideration of human and environmental factors more commonly examined by the social sciences [19]. In this paradigm, the designer must excel at: empathy, integrative thinking, optimism, experimentalism and collaboration, as well as self-reflection [23], [24], [24] to better understand the dynamic interactions between designers, users and their environments [18].

Design thinking is inherently a user-oriented activity underpinned by the user-centred design (UCD) methodology. UCD aims to realize the goals of usability through the careful and empathic consideration of user-needs, experiences, environments and other contextual elements at every stage of the design process. Recently UCD has become a widely employed framework in many fields of research and has been adopted as a central tenet of disciplines concerned with technology design, such as, human-computer interaction (HCI), that have recognized

the need to address design-spaces from the point of view of user-experience [25] .

As the field of HCI has matured and incorporated design practices, there have been calls to address key issues regarding the consolidation and integration of design knowledge into this traditionally scientific field [26]. The purpose of this integration, as with most intellectual disciplines, is to form conventions and standards that unify a field under an identity and provide legitimacy to practices within it [26], [27], as well as to produce coherent language to describe and scrutinize research under a common banner. However, due to the interdisciplinary nature of design practice, as well as its tendency to produce results that embrace ambiguity and the ill-defined nature of many design problems such formalizations are not possible and indeed counterproductive to the goals of UCD and design in general. Despite the relative resistance HCI presented at first, practitioners have been quite successful in addressing the incorporation of design-based practices into the field by pushing for an abandonment of the 'scientism' in HCI culture and instead explore mechanisms to transform the ambiguous data that design-based research in HCI produces, into actionable paths towards design [25], [26], [28].

As such, UCD has proliferated within HCI and resulted in an interdisciplinary and dynamic field of research embracing innovative frameworks and methods. Two recent examples of such frameworks can be seen in the emergence of ecological and embodied approaches to design within HCI. These two notions, grounded in psychology and cognitive science, offer fresh perspectives on how to better understand user experience, perception and behaviour in their natural environments. In the following section we present an account of these two concepts to frame current UCD approaches within HCI and design.

2.3. Ecological and Embodied approaches to Design

The ecological perceptual theory proposed by James Gibson in 1966, came as a reaction to the dominant cognitivist information-processing mentality at the time. Gibson rejected the idea of the world as a chaotic source of meaningless sensory stimuli, onto which perceiving organisms impose structure and meaning through acquired mental representations of the world within their cognitive apparatus [29]. He instead approached perception from a unique perspective for perceptual and cognitive science, by emphasising the situatedness of the perceiver in a naturally structured environment, full of ambient information and controlled by the laws of physics [30]. He characterized perception as an active and exploratory state, constantly orienting the organism towards the environment through action, in order for the organism to respond accordingly to the highly complex, but organized features of said environment. As such, perception here is considered a self-tuning/adapting process in which the discernment of environmental information by sensory organs reinforces and optimizes the perceptual system, tuning it more and more to the subtle invariant features of the evolving yet stable environment it inhabits [5].

Arguably the most fundamental concept introduced by Gibson's ecological approach is the ideation of *Affordances*. Affordances provide a mechanism for understanding the interrelation between the environment and perceiver, by explaining how the inherent/invariant properties of objects in the environment and the context of what is occurring *affords* the perceiver with cues on how to regulate its behaviour appropriately in regards to the context without the need of any prior knowledge or cognitive process [31]. The ecological approach makes no distinction between the natural and the cultural environment. As such, perception is not limited to physical objects, and it is possible to extract actionable meaning from abstract phenomena such as language, sounds and symbols [5]. By emphasizing the situatedness of a perceiver in a larger sensory-rich environment through the perception-action cycle, Gibson's account of perception, not only highlighted the importance of a perceiver's ecology in cognition, but also nurtured the notion of embodiment.

Up until developments in psychology and philosophy of the mind during the 1960s, the cognitive sciences had traditionally viewed the body of a perceiving organism as peripheral to cognition. However, through the proposition of embodiment, cognition began to be viewed as intrinsically dependant on aspects of the perceiver's body other than the brain, resulting from its existence in an environment requiring both sensing and acting [30].

Today, in the current technological landscape of wearables, virtual/augmented reality and the Internet of Things, the body has become of central concern for design as we seek to expand its boundaries and capabilities. As such, embodied design aims to leverage the user's body and its experience as a whole to inform design ideation [32]. The assets afforded to designers by the ecological and embodied approaches discussed here are of great importance in developing comprehensive user-centric design frameworks, particularly in perceptual research like AD, whereby the interrelationship between users, environment, body and product can be carefully scrutinised in order to make appropriate design decisions [33].

3. IMPLICATIONS FOR AUDITORY DISPLAY

From the descriptions of usability and aesthetics in AD, Design thinking and user-centric design in HCI, as well as ecological and embodied approaches to design, it can be seen that the field of auditory display shares many common threads with these disciplines. A common theme that emerges from the discussion in this paper, has been the progressive rejection of positivist approaches in different fields as mentality shifts towards user-centric ideas. This common evolution within disciplines, concerned with the production of new technologies and products, suggests a certain degree of desirability in integrating design-based approaches, despite obvious tensions that arise from traditionally opposing philosophies.

Interestingly the adoption of user-centric approaches to design seen in HCI has been much slower for AD research. Only until recent editions of the International Conference for Auditory Display have we begun to see explicit examples of user-centric approaches such as participatory design [34], [35]. In these examples we begin to observe the recognition of the potential of user-centric approaches in AD, as well as the use of the associated vocabulary and techniques already established within fields such as HCI and Design. This suggests an ongoing convergence amongst these fields of research, that may ultimately help homogenize the language and approaches employed in AD research, with the aim of producing a more coherent

discussion and exploration of the issues this field is faced with.

An initial example of this clear shift in focus towards user-centric approaches in AD can be observed in the work of Stephen Barras [8]. In this work Barrass uses the example of how, what he terms the 'aesthetic turn in visualization', acted as a catalyst for innovative, participatory and user-centric approaches in the field. However, more importantly Barras describes how this aesthetic turn empowered individuals outside scientific and engineering disciplines to engage socially in producing novel and more personally relevant data visualizations. He proposes that for AD to experience the effects of such an 'aesthetic turn' in the field, design-based approaches are the most suitable for "*dissolving division between scientific and artistic methods*" [8] and producing AD designs that are usable and of mass-appeal.

Further evidence of the use of user-centric approaches that push the AD field in the direction envisaged by Barrass, is exemplified in the work presented by Wolf et al. [15]. Wolf et al. present a sonification approach aimed at decentralizing AD design by providing end-users with a sonification system that can be tweaked and refined after the initial implementation by the researchers. This is achieved by providing users with an interactive semi-autonomous sonification system, based on previous well documented sonfication techniques, that produces an initial base 'soundscape' for which users can then modify the sonification mapping parameters to suit their preferences. In this paper the authors make explicit their adaptation of techniques from HCI to develop a UCD approach to sonification. However, despite the potential of UCD highlighted in this paper, the authors acknowledge the need for further in-depth investigation of methodologies akin to the one they present.

In the two examples discussed above, we see clear evidence of UCD approaches developing in AD. Further examples can be found that trace the convergence of HCI and design methodologies with AD in the work of Goudarzi [7]. In this paper the author makes use of the participatory design workshop method for developing UCD oriented sonifications. This paper is of interest to this study, as it makes direct use of an HCI/design-based tool, for achieving UCD in sonification design. In the workshop, the authors aimed at creating a dynamic environment between AD designers and end-users based around dialogue and interaction. This dialogue provided a means of elucidating the common threads and frictions between designers and users. This common ground served as a basis for the cultivation of a symbiotic design relationship at the hands of the end-user. The authors describe the challenge of placing users and designers in direct contact with each other to produce participatory design. However, their results suggest that the workshop model provided an adequate mediation for producing a greater appreciation for each other's perspectives and engendering the desired user-designer relationship [7].

Finally, while we have observed a clear causality between the emergence of aesthetic considerations in AD and the development of UCD approaches, we can further observe the convergence of AD with the more current trends in HCI research in the work of Landry and Jeon [35]. In this paper the authors employ a participatory design methodology that is heavily focused on the situatedness and embodiment of the user. By placing direct emphasis, not only on the user's needs, but on the actual physical experience of the user's body within its environment as a source of design knowledge, this work presents a unique example of embodied and ecological design in AD. The authors highlight the complexity and unfamiliarity of employing this particular approach for the design of an auditory interface but encourage further exploration thanks to the rich source of data derived directly from end-users. As such, despite the difficulties faced by the researchers in implementing this approach, this paper serves to further highlight the recent convergence of AD and HCI theory, vocabulary and technique in the context of our discussion of ecological and embodied design of AD.

While relatively new to the discussion in AD research, notions of ecological and embodied approaches are not entirely unfamiliar to the field of auditory research. One clear historical example is the notion of listening modes envisaged by Pierre Schaeffer and refined by Michel Chion [36], [37]. In his *Traité Des Objets Musicaux: Essai Interdisciplines*, Schaeffer formalizes his ideas on the listening state of mind by introducing a taxonomy of 4 distinct modes of listening: *écouter, entendre, comprendre and ouir*. This categorization laid the groundwork for modern musicological research into the listening and perception of organized sound. Since the *Traité Des Objets Musicaux,* the taxonomy of listening modes has been variously expanded and reduced in different attempts at reconciling some of the more obscure aspects of Schaeffer's original depiction and adapting it to more modern perspectives of music perception [37], [38].

As the overall philosophy and approach to AD design has shifted towards trying to better understand users' listening experiences, the discussion around the listening mode taxonomy initially proposed by Pierre Schaeffer has become of great relevance to the field [10], particularly from an ecological point of view, as this conception of listening aimed at creating an understanding of how listening is affected by different contexts. Other examples of ecological considerations in AD can be found in attempts to apply Gestalt Theory to understand how design auditory displays that discretely fit in within their environments [39].

From these instances and throughout the discussion in this paper, it can be observed that the AD community has been shifting towards more user-centric approaches in recent times. However, while much attention has been given to understanding the listener in the domain of music and organized sound, the same cannot be said of AD research [40]. This is of particular importance as greater emphasis on user-experience has become paramount to current AD design. As such, we believe it is important to encourage AD practitioners to explore UCD as a tool for producing vibrant and innovative research. Furthermore, we encourage the implementation of ecological and embodied frameworks as tools for engaging users fully and directly in their environments, with the aim of creating more meaningful dialogues between designers and end-users. We hope that through this discussion we have emphasised the need to address key usability concerns in AD and presented a theoretical background to do so.

4. CONCLUSION

In this paper we framed the current state of affairs in auditory display research by contextualizing and elucidating the user experience and usability concerns within the field. We provided a background into the emergence of key design-based approaches, namely design thinking and user-centric design, and their critical role into human-computer interaction studies. We also introduced the ecological and embodied approaches to design, as innovative elements for informing the design of AD applications in order to support better usability and user experience. Through the discussion in this paper we hope to encourage AD designers to experiment with the approaches discussed herein.

5. ACKNOWLEDGMENT

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