Characterising Soundscape Research in Human-Computer Interaction

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ABSTRACT

'Soundscapes' are an increasingly active topic in Human-Computer Interaction (HCI) and interaction design. From mapping acoustic environments through sound recordings to designing compositions as interventions, soundscapes appear as a recurring theme across a wide body of HCI research. Based on this growing interest, now is the time to explore the types of studies in which soundscapes provide a valuable lens to HCI research. In this paper, we review papers from conferences sponsored or co-sponsored by the ACM Special Interest Group on Computer-Human Interaction in which the term 'soundscape' occurs. We analyse a total of 235 papers to understand the role of soundscapes as a research focus and identify untapped opportunities for soundscape research within HCI. We identify two common soundscape conceptualisations: (1) Acoustic environments and (2) Compositions, and describe what characterises studies into each concept and the hybrid forms that also occur. On the basis of this, we carve out a foundation for future soundscape research in HCI as a methodological anchor to form a common ground and support this growing research interest. Finally, we offer five recommendations for further research into soundscapes within HCI.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**.

KEYWORDS

Soundscape, theory, sounds, audio, literature review

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1 INTRODUCTION

Sound has played an increasingly substantial role within Human-Computer Interaction (HCI) and design research and practice for several decades. Since Gaver's seminal work on using auditory icons to represent data about the world in a way that builds on users' existing listening habits [86], the field has steadily expanded. Typical application areas include variations of Gaver's work, *i.e.*, the investigation of sound for its capacity to represent data or the usefulness of sound in giving feedback about system states or supporting interaction with systems. Although this testifies to a long history of investigating sound in HCI, sound-oriented research has only within the last decade expanded to include sound as the primary interaction medium as opposed to taking up a supporting role [81]. Here, soundscapes have often played a prominent role in a variety of research and use cases. Despite the long-standing role of sound in HCI, prior work has also criticised how HCI researchers embed sound in their research. Droumeva and McGregor argued that HCI designers' lack of training in sound design can result in not taking listeners' experiences into account in the process of sound design [61]. As such, sound is sometimes considered as an afterthought and does not follow best practices.

In this paper, we investigate how HCI and design researchers present work on soundscapes to provide a conceptual and empirical starting point for future research and design. Schafer describes soundscapes broadly as "[...] any acoustic field of study" [229]. He adds that "We may speak of a musical composition as a soundscape, [and] We can isolate an acoustic environment as a field of study" [229]. Complementary to this, Truax states that he "[...] will use the term "soundscape" to put emphasis on how that environment is understood by those living in it" [255]. As such, soundscapes are collections of sounds experienced as a whole and thereby provide the opportunity to create interactive and engaging experiences that are different from other sound-based experiences. Soundscapes offer a new addition to the toolbox of HCI researchers and practitioners, with the potential to contribute new knowledge into designing interventions into acoustic environments or through compositions. This potential, however, is far from utilised, as indicated by the continuous lack of conceptual coherence [129]. The reasons for this are, however, unclear.

To provide a better understanding of the current use of soundscapes, and with the goal to improve the design, methods, and reporting within this emerging area of inquiry, we set out to systematically review soundscape research in HCI. Our main focus has been to understand how soundscapes are currently conceptualised and investigated. Through the review, we have identified and assessed papers from conferences fully or co-sponsored by the ACM SIGCHI. Our analysis, which is based on a selection of 235 articles, focuses on how the term soundscape is used, the theoretical background on which researchers rely, how and in which formats researchers share their research data, and the methods authors employ to capture soundscapes to understand and design for them.

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Our results highlight that current work on soundscapes relies only sparingly on shared definitions. This inherently results in a haziness in research papers which prohibits positioning of the presented work in relation to related research. Given the relatively recent uptake of soundscapes in HCI research, we argue that a clearer definition of soundscapes is key to evolving the field. For example, we find that the disparity between designing for sound and designing a soundscape is rarely explicit in HCI research. The use of unclear definitions muddles scientific progress and collaboration, as for example seen in prior work on the semantic confusion around 'affect' and 'mood' [205]. The main contributions of our paper are:

- An extensive review of current HCI studies utilising the concept of soundscape. We highlight two main variations of conceptualising soundscapes (acoustic environment and composition), which we further distinguish into three subcategories, respectively.
- Identification of study methods and data gathering and sharing practices for soundscape studies in HCI.
- Two informed research spaces in which further soundscape research and design can be anchored.
- Five recommendations for future soundscape research within HCI, focusing on clear definitions, environmental characteristics, methods for engagement with soundscapes, and the including and sharing of research materials.

2 RELATED WORK

In our aim to review HCI studies utilising the concept of soundscape, we recognise that our work fits into the broader research area of sound in HCI. Furthermore, research on soundscape has a long history in the related area of sound studies, from which HCI researchers have brought in useful definitions and methods. Therefore, we provide an overview of sound design in HCI and soundscape research more broadly to set the stage for later discussions of the findings from our literature review.

2.1 Sound Design in HCI

As stated in the introduction, sound has played different roles in HCI research throughout the past decades. Here, we review some of the most prominent areas, including auditory displays, musical interfaces, and acoustic environments (virtual and real). This research spans investigations that focus on both listening to sounds and designing sounds.

Originating in the 1980s, so called auditory displays have been developed to present data in the form of sound or support interaction with a visual interface with sound [86]. A recent example is described by Tomlinson et al. [252] who showed that learners with visual impairments benefited from an auditory display for science simulations. Early research on sound within HCI includes Gaver's seminal paper on auditory icons [86]. The basis of this work was to explore how sound can be used to convey information to users based on its symbolic character. Gaver argued that sound in computer interfaces should be designed based on the way users already listen to the world. Later, in his doctoral dissertation, Gaver distinguishes between everyday and musical listening [87]. While musical listening is about paying attention to the sound itself, everyday listening directs the listener's attention towards the event which created the sound. Even though Gaver's research on auditory icons is well-cited, sound remained a mostly neglected medium the following two decades [81]. This prompted the emergence of a sub-discipline termed 'Sonic Interaction Design' (SID) with the aim of moving beyond sound as a merely functional and signalling aspect of interaction. A central anchor to this sub-discipline is the book edited by Franinović and Serafin [81], published in 2013 and covering topics and case studies revolving around SID.

At its core, SID revolves around the relationship between a user and sounds through interactive technology, especially focused on sound as feedback. This sub-discipline builds on a number of subjects at the intersection between ubiquitous computing, interaction design, auditory displays, and interactive arts. To put emphasis on the lack of investigations into auditory communication modalities, Rocchesso et al. facilitated a workshop during the SIGCHI Conference on Computer-Human Interaction in 2008 [223]. The SID community has since underlined the importance of designing for embodied and multimodal experiences [81]. This is especially interesting in HCI with the development of tangible interfaces, enabled by physical computing tools. Related to this, advances have been made in sound and music computing, where *e.g.*, novel physical interfaces are developed for musical expression. One example of this is the mixiTUI interface [211], a sequencer for importing music and performing live through tangible tokens.

Building on the importance of embodiment in designing sonic interactions, Caramiaoux et al. [30] presented a participatory technique to aid designers. This technique is based on aiding users in accessing memories of sound events and imagining scenarios where they change the events. For a similar purpose, Houben et al. [119] designed a 'soundboard' to evoke memories of people with dementia through personal associations with different sounds.

Within recent years, sound has taken up a prominent role in a wide range of HCI-related works. This includes expanding the focus on embodiment, *e.g.*, to use sounds to simulate co-located experiences [109], as well as for a proposed 'sound-driven design' approach to externalise tacit expert knowledge [51], to name just two examples. In this paper, we focus specifically on soundscapes – an area with a rich history outside of HCI but which is currently also expanding within our community due to increased audio technological possibilities and the desire to provide immersive and embodied experiences. A recent example is presented by Haas et al. [100] who investigate ways of curating 'personal soundscapes'. They show that different audio technologies (such as hear-through or noise-cancellation) result in either mediated or augmented reality experiences. Similarly, location-based earcons or sound recordings can be used to create mediated or augmented virtuality experiences.

2.2 Soundscape Beyond HCI

Soundscape research has a broad, multi-disciplinary history which cannot be covered in-depth here. We therefore cover general takeaways from the establishment of the field to now. Soundscape research today, both within and beyond HCI, is heavily anchored in the World Soundscape Project (WSP) which was established in the 1960's at Simon Fraser University in Vancouver [229]. When the acoustic environment of a place, whether physical or virtual, is studied, the collection of sounds is often referred to as a 'soundscape'. In

a particular aim to study the relationship between people and their acoustic environments, researchers within the WSP established the field of acoustic ecology [229]. Schafer and Truax were both central to the establishment of this field of research. While not the first to use the term 'soundscape', Schafer [229] is typically attributed for his definition of soundscapes as consisting of three key features, drawing on features of landscapes, although his definition is broad and therefore remains largely open to interpretation. He offers an analytical approach to soundscapes by categorising the features of a soundscape into 'keynote sounds', 'signals', and 'soundmarks'. Keynote sounds are fundamental to a composition of sounds and set the tone on which other sounds are experienced. Signals, on the other hand, are in the foreground of listeners' attention. Finally, soundmarks have special cultural meaning in specific communities. Complementary to this, Schafer writes on music that "In absolute music, composers fashion ideal soundscapes of the mind" [229]. Therefore, with this approach, a soundscape can be understood as both the acoustic environment and musical compositions.

The definition of soundscapes by Schafer has later been criticised for being vague, leading to methodological disagreements [144]. In addition to that, Kelman [146] criticised current (in 2010) use of Schafer's concept of soundscapes. He pointed out the ideologies in Schafer's work, for example which (types of) sounds should be present and which (types of) sounds should not. Even so, Schafer's definition is still widely used as the starting point for much research in studying, composing, and designing interventions into soundscapes. Schafer offered a view on soundscapes as technologically mediated, meaning that any recording is constrained by the microphone technology used to record and the speaker technology used to reproduce the sounds. Going further, Truax saw sound itself as a mediator between the world and a listener [255]. In his work on 'acoustic communication', he emphasises that soundscapes are experienced by someone. With the definition of soundscape as a perceptual construct, a human-oriented approach is introduced, shifting attention from sound sources to human engagement with sound.

Building on Schafer and Truax, as well as criticism presented in more recent work, Brown et al. [25] offer further precision of the term from the perspective that a soundscape is part of a physical environment. They write: "A soundscape exists through human perception of the acoustic environment, but it is appropriate to utilize the term soundscape of a place to represent both "the acoustic environment as perceived by humans" as well as "the total collection of sounds" of a place. The latter use needs to be restricted to identification or measurement of those sounds by the ear, to avoid devaluation and misuse of the term." Studies they analyse typically aim to examine (1) the relationship between humans and their acoustic environment, (2) soundscape quality, (3) soundscape preference, (4) "human acoustic comfort", and (5) soundscape improvement (soundscape design).

An International Standard was established in 2014 [129], three years after Brown et al.'s publication, in recognition of the growing challenge of reaching a general consensus on the term. The standard defines soundscape as a perceptual construct, developed in steps of first auditory stimulation and subsequent interpretation. The model explicitly emphasises that the context in which sounds are experienced affects both of these aspects. The understanding of soundscapes as perceptual constructs is the most widely used within environmental design and urban development [26, 76].

Much research on soundscapes focuses on outside areas, but it is increasingly recognised that the effect of the environment on the way sounds are experienced should also be considered. To complement the focus on outdoor areas such as city squares and parks, Kang and Schulte-Fortkamp [144] edited a book in 2016 focused on built environments. This follows a related emerging area of 'aural architecture' looking beyond the physical properties of a space [15]. In the book, Brown et al. further detail the classification scheme presented in the International Standard and suggest that it can be used to standardise reporting of acoustic environments. Another classification scheme for designing and evaluating 'augmented auditory environments' is proposed by McGregor et al. [184]. This includes establishing the dimensions that are used to describe such experiences by audio professionals and end-users. Another example of developing tools for 'soundscape mapping' is presented by Droumeva and McGregor who argue for more "...ecological notions of listening and focus on how people attend to and make sense of their everyday soundscapes" [61]. The above cited research is founded in the area of acoustic ecology as initially developed within the WSP project. This more recent work shows the necessity and relevance of relying on more rigorous tools and common conceptualisations.

3 METHOD

In this section, we outline our method for conducting a review on the use of theory in grounding soundscape research in HCI in the last 20 years. With this in mind, we focused on the conceptualisation of soundscape as presented by authors and the definition this conception is based on (as either retrieved from previous research or formulated by the authors).

We followed a structured search strategy as inspired by the PRISMA-ScR framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) [254]. This framework provides guidance in the structured identification of relevant literature, which supports our goal of making our approach replicable by other researchers. We next describe the steps taken in literature identification, screening, our inclusion criteria, and our exclusion criteria.

As sound plays a role in many HCI studies, we cast a wide net in covering the HCI landscape. We include all conferences that are sponsored or co-sponsored by the ACM Special Interest Group on Computer-Human Interaction, more commonly known as SIGCHI. This provides a wide overview of the field, including both general conferences (*e.g.*, CHI) as well as domain-specific conferences (*e.g.*, AutomotiveUI). Our search included a total of 23 conferences, for each conference including the initial proceedings up to the last proceedings available[1]. We explicitly chose not to include any journals

[1]We include the following conferences and proceeding years; *AutomotiveUI (Automotive User Interfaces and Interactive Vehicular Applications*, '19–'20), *CHI (Human Factors in Computing Systems*, '81–'21), *CHIPlay (Computer-Human Interaction in Play*, '14–'20), *C&C (Creativity & Cognition*, '99–'21), *CSCW (Computer-Supported Cooperative Work and Social Computing*, '86-'20), *DIS (Designing Interactive Systems*, '95–'21), *EICS (Engineering Interactive Computing Systems*, '09–'21), *ETRA (Eye Tracking Research and Applications*, '00–'21), *GROUP (Supporting Group Work*, '97–'20), *HRI (Human-Robot Interaction*, '06–'21), *ICMI (Multimodal Interaction*, '02–'20), *IDC (Interaction Design and Children*, '03–'21), *IMX/TVX (Interactive Media Experiences*, '16–'21), *ISS/ITS (Interactive*

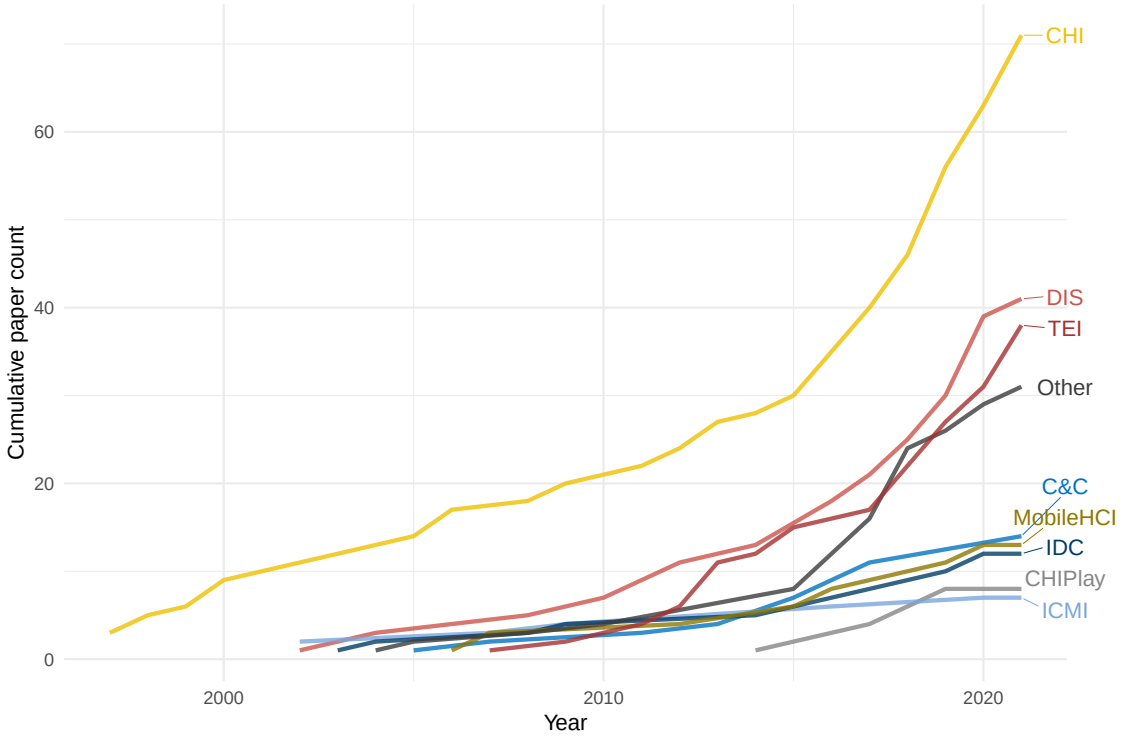

Figure 1: Distribution of identified articles across the 23 SIGCHI (co-)sponsored conferences

given the lack of a uniform search engine to search across HCI journals, the challenge in defining a set of relevant HCI journals, and the often different focus of journal articles than conference papers. The selected conferences represent the wide spectrum of HCI research and therefore make for a relevant and interesting corpus. We use the ACM's digital library to search each of these 23 conferences for use of the words 'soundscape', or 'soundscapes' in either the title, article text, or meta-data (*e.g.*, keywords). This resulted in a total of 416 articles. We subsequently manually went through the paper list and excluded any paper in which soundscape was merely mentioned as an element of related work or in which the word 'soundscape' simply appeared in the title of a reference or a referenced product (*e.g.*, 'Microsoft's SoundScape' and 'VRSonic's Soundscape3D'). We also excluded papers where soundscape was only mentioned as a potential direction for future research with no specification on how this would be investigated. Finally, we excluded one Doctoral Consortium paper which duplicated the description of soundscape from a related late-breaking work paper on the same study.

This resulted in our final list of 235 articles that we analyse in-depth in the remainder of this article. The analysis was conducted in three iterations between two researchers with a shared spreadsheet (uploaded as supplementary material to this paper). An overview of the distribution of the articles per conference is presented in Figure 1. As can been seen from the figure, a large number of articles originate from the CHI conference, the premier and largest conference in the field, followed by DIS and TEI—two conferences with a strong design focus. Given the relative size of the DIS community and proceedings in relation to CHI, the prominence of DIS papers in our search highlights the relevance of our work to this conference. Table 1 shows the collected data for every manuscript.

To supplement our qualitative analysis on usage of the term soundscape, we conducted a quantitative content analysis of the entire corpus. Our goal in this analysis is to obtain a better understanding of the way 'soundscape' is used as a term in the research community. As preparation for this analysis, we conduct the following three steps. Firstly, we import all PDFs previously identified as relevant and extract their text using *tabulizer* for R [167]. Secondly, we removed all stop words from the text due to their limited information value (*i.e.*, words such as 'an', 'also', and 'of'). Finally, we standardised all occurrences of the word 'soundscape' (*e.g.*, 'soundscapes', 'sound scape') to allow for comparison between papers. Following this preparation, we identified words that were directly adjacent to the word 'soundscape'. These sequences, known as bigrams, can tell more about the way in which soundscapes have been described in prior work.

Surfaces and Spaces, '11–'20), *IUI (Intelligent User Interfaces*, '93–'21), *MobileHCI (Mobile Human-Computer Interaction*, '05–'20), *RecSys (Recommender Systems*, '07–'20), *SUI (Spatial User Interaction*, '13–'20), *TEI (Tangible, Embedded and Embodied Interaction*, '07–'21), *UbiComp (Ubiquitous Computing*, '01–'20), *UIST (User Interface Software and Technology*, '88–'20), *UMAP (User Modeling, Adaptation and Personalization*, '11–'21), *VRST (Virtual Reality Software and Technology*, '96–'20).

Table 1: List of data collected from each paper

	Metadata	Description
Manuscript details	Publication venue	-
	Year published	-
	Full text	-
Content details	Soundscape reference	Do authors include a reference for soundscape?
	Soundscape definition	Do authors provide their own definition of soundscape?
	Method for documentation	Do authors utilise a method for documenting the soundscape?
	Sensor input	Is the soundscape affected by sensor input data?
	Co-words	Which words are typically used together with 'soundscape'?
Data sharing	Resource type	Which supplementary material is shared by authors?

4 RESULTS

In this section, we present the collected findings in relation to the different conceptualisations of soundscape, documentation methods utilized by authors, and resources as provided by authors. We provide an overview of the categorisation of each paper in Table 4 in the Appendix.

4.1 Conceptualisations of Soundscape

4.1.1 Relying on a Definition of Soundscape. We found that most papers do not rely on either a definition from prior research nor on a definition formulated by the authors themselves. A small minority of 15 papers (6.4% of the analysed papers) refer to a definition of soundscape from prior research. In 12 of these, research by Schafer is used as a source. As could be expected from the use of Schafer's inclusive definition, the types of studies cover a wide range of applications of the term, including making compositions and studying natural, acoustic environments. This ambiguity can also be found in papers where soundscape is described in conflicting terms with no reference. For example, Budtz and Jung write that "The soundscapes used in our approach are musical compositions with a fixed core and a certain number of optional elements" but also that "notifications for a limited set of employees could be seamlessly integrated into the existing soundscape", implying that a soundscape is understood as both a composition and an acoustic environment [27]. Of other referenced material, we found a sourcebook of auditory effects that builds upon Schafer's research [7], as cited by Kinch et al. [96]. We found 16 papers (6.8% of the analysed papers) in which authors formulate a definition or where the authors offer an example of what a soundscape is within the scope of the paper without an explicit reference to prior research.

Definitions made between these 31 papers span a broad range of terminology for soundscapes. We summarise them into three categories:

- As digital overlay to the physical world, *e.g.* [272, 277]. Example: "[...] one way of thinking about 'soundscapes' is to imagine the emergence of new, digital dimensions overlaying the physical world." [277]
- As an auditory or acoustic environment that is either real or virtual, *e.g.* [59, 141, 200, 231, 282]. Example: "Soundscapes are made up of many sounds in interplay with each other. These include ambient sounds that are present most of the time, sound signals that attract attention, and soundmarks, which characterize acoustic spaces." [59].
- As a composition made of either a combination of natural and synthetic sounds or a mix of natural sounds, *e.g.* [164, 185]. Examples: "[...] all the sounds of the game are organized as a soundscape" [185] and "Continuous soundscapes are background or atmospheric sounds embedded with information describing mostly low urgency or non-time-sensitive information." [164].

Four papers use soundscape to describe the sound composition of how an isolated object or place sounds, but do so implicitly. For example, "[...] an artificial vehicle soundscape that play at a continuous, low-level in the background of the vehicle" [134], and "The plastic marbles rolling on a wooden board created a distinct soundscape [...]" [6]. Another example is the use of heart rate data to update the flow from a water pump, resulting in varying sounds of falling water [69]. For some descriptions of soundscape as a composition, soundscape is considered a collection of individual sounds. *E.g.*, Wang et al. [274] write: "[...]players had to consistently engage with the ice cream, which created almost a soundscape rather than individual sounds."

Soundscape is sometimes distinguished from music but not in a way that explicates the difference. *E.g.*: "They interact with the system by manipulating the lighting of the space where it is experienced, the music that is playing in the background, the ambient soundscape of the experience, and [...] an ambient video [...]" [98] and "[...] we distinguish between what we call rhythmic music involving notes and rhythms and abstract music constituted of more soundscape like sounds" [132].

In summary of the above, the identified 31 out of the 235 papers (13.2% of the analysed papers) provide a definition of soundscape that is either founded in prior research or formulated on the basis of the study presented. A total of 204 papers did not include a reference to a prior definition or a description of what a soundscape is conceived as. Moving further into the perceptions of soundscape, we look more broadly at conceptualisations with or without an explicit definition.

4.1.2 Soundscapes as Acoustic Environments or Compositions. We categorise each of the 235 papers in our corpus based on their perception of soundscapes. Here we distinguish between two main categories: papers that refer to a soundscape as an acoustic environment and papers that refer to soundscape as a composition. Each main category is further distinguished in three subcategories. We provide an overview of the conceptualisations uncovered from all papers in Table 2.

Real-world [Acoustic environment]. In the first subcategory within 'Acoustic environments', 'Real-world' refers to soundscape as a real, acoustic environment. In the 46 papers (19.6% of the analysed papers) identified in this subcategory, a physical environment is studied. Environments include but are not exclusive to: outside nature, homes, and factory work settings. Nine of the papers included in this category either refer to Schafer's definition of soundscape as an acoustic environment, include a reference to Truax, or both [60, 100, 139, 169, 185, 201, 209, 242, 265]. Of these nine, two actively utilise the aspects of soundscapes described by Schafer, *i.e.*, 'keynote', 'signal', and 'soundmark' [139, 201]. In addition to this, these nine papers use the references to position the research as investigations of acoustic environments. In one paper, the author refers to the 'internal soundscape' of participants' bodies as an acoustic environment [232], meaning sounds coming from inside the body, *e.g.*, a heartbeat. Beyond that paper, the acoustic environments are environments surrounding one or more persons.

Simulated with speakers [Acoustic environment]. A total of 20 papers (8.5% of the analysed papers) were identified in this subcategory. Studies where soundscapes are simulated acoustic environments, either with speakers or virtual/augmented reality, often focus on creating a spatial dimension of the sound. For the subcategory 'Simulated with speakers', a real acoustic environment has either been recorded or composed with the purpose of simulating it in other settings. One example is simulating the acoustic environment of a car, *e.g.*, as presented by Smith and Nayar [239] to support visually impaired people in playing racing games, or as presented by Goedicke [89] for a virtual driving simulation. Other examples include, *e.g.*, playing soundscapes of landscapes in a dementia care facility to elicit memories [120] or in a school setting to promote childrens' storytelling competences [46].

Virtual or augmented reality [Acoustic environment]. For virtual reality applications, the creation of soundscapes is either done by mimicking the spatial properties of real environments or by playing isolated audio sources from perceptually different directions [114, 196]. For augmented reality applications, digital layers of sound are added to the existing acoustic environments to, *e.g.*, provide information about points of interest within a geographical area [154, 183].

Musical or Ambient [Composition]. Soundscapes as musical or ambient compositions are used in different ways. Compositions in this subcategory of 78 papers (33.2% of the analysed papers) only consist of digitally created sound, either composed before users engage with it or composed by users as part of a study. In this context, we categorise sounds from musical instruments in digital libraries used, *e.g.*, to sonify specific types of interactions [288] or as a customized audio sequence [212] as created digitally. In 45 cases, musical or ambient compositions are created from sensor output, *e.g.*, sonifying haptic interactions with conductive feathers [22] or modulating a composition from live EEG data [38]. Soundscapes are also used to describe musical compositions that represent a specific time and place. Chu et al. describe their use of soundscapes for prototypes that elicit historical, sensory experiences: "The soundscapes provide information about a time and place that is difficult to communicate through text alone. For example, the music was chosen to offer a clear contrast between the homophonic secular music of the time and some of the polyphonic sacred music of the Franco-Flemish school" [40].

Mix of real-world recordings [Composition]. This subcategory includes 27 papers (11.5% of the analysed papers) where soundscape is perceived as a mix, or composition, of real-world recordings. This includes research where recordings are mixed for virtual reality to, *e.g.*, "[...] create natural, contextual soundscapes" [103]. In one paper by Stepanova et al., this application of soundscape is utilised by having users immerse themselves in a virtual reality underwater experience. In other papers, sound recordings are composed into a soundscape through processing sensor input and playing a resulting composition, *e.g.*, as presented by Hendriks et al. who designed an interactive cushion which produces sounds of fire, water, and singing bowls when moved [109].

Mix of real-world and digital sounds [Composition]. This subcategory includes papers where soundscape is perceived as a mix of real-world recordings and digitally generated sound. Only 10 papers (4.3% of the analysed papers) were identified in this subcategory and out of those, four were full papers. The papers differ in their application of soundscape. One presents a prototype design of an auditory interface which sonifies elements of a GUI [131]. The sounds included both audio samples of wind, trees, etc., as well as musical notes. Another example is presented by Aylett et al. [9], who build on Weiser's vision for calm computing and propose a system for delivering peripheral information in the form of a 'personalized radio service', playing sound recordings and music.

Unspecified. For 15 papers (6.4% of the analysed papers), we could not infer a conceptualisation of what a soundscape was perceived to be by the authors. We found one paper where the term is used in a definition of sound but not explicated itself. The authors write that: "[...] sound is seen as a ubiquitous communication channel between listener, soundscape and a physical (and cultural) environment." [62].

4.1.3 Co-word Content Analysis. In Figure 2, we present unique bigrams with an occurrence of six times or more across the entire corpus, highlighting the most common bigrams. As can be seen in Figure 2a, the most common bigrams are 'ambient soundscape', 'domestic soundscape', and 'nature soundscape'. These are descriptions of soundscapes that are mostly open to interpretation, aligning with

Table 2: Examples of Soundscape Conceptualisations

Soundscape Conceptualisation	Subcategory	Example
Acoustic environments (105)	Real-world (46)	"We extended the design with a variety of playful interfaces to learn, explore, and discover in wilderness soundscape recordings." [53]
	Simulated with speakers (20)	"[...] a participant standing in the middle of the array would hear different audio tracks coming from many directions, thus generating a real-like environmental soundscape" [149]
	Virtual or augmented reality (39)	"[...] the real acoustic environment is mixed with a virtual soundscape and returns to the listener as "pseudoacoustic" environment" [192]
Compositions (115)	Musical or ambient (78)	"For example different chemical elements could be played using a different musical instrument or voice to give wall displays the pleasant soundscape of a choir" [187]
	Mix of real-world recordings (27)	"[...] the pair of Azaleas produce a shared soundscape in constant flux, composed of fire, water, and singing bowl" [176]
	Mix of real-world and digital sounds (10)	"a soundscape is generated that mixes stereo speech synthesis output with sound effects, background music, and short (10 sec) audio adverts" [9]

our earlier observation that the use of the term soundscape is broad and applicable to a number of different types of studies. 'Ambient' refers to both soundscapes as environments, *e.g.*, for mixed reality systems where audio is used as a navigation tool [155], and to soundscapes as compositions, *e.g.*, for providing a supporting background to particular activities [130]. 'Domestic soundscape' occurs several times in two papers by Oleksik et al. [200] and Johansen & Nielsen [139]. These papers focus on studying and designing interventions into the acoustic environments of homes. Furthermore, Oleksik et al. provide a definition of domestic soundscapes extending Schafer's definition. Other particular environments reported in Figure 2a include 'nature' and 'urban'. For these occurrences, no definition of the particular soundscape is offered. Like the coword ambient, the bigram 'nature soundscapes' is either used for acoustic environments, *e.g.*, when engaging with wilderness environments [54], or for compositions, *e.g.*, when mixing nature audio recordings to create a soothing background composition [197].

The most common occurrences for bigrams in Figure 2b are 'soundscape design' and 'soundscape data' with 12 and 10 occurrences, respectively. Soundscape design is used in studies that involve, *e.g.*, engaging children in exploring local sites through recording and mixing sounds [279] as well as mapping a design space for interactive auditory mediated experiences [100]. While Haas et al. describe that their approach yielded different requirements than "[...] current soundscape design approaches" [100], no reference is provided to suggest what such approaches entail. Finally, we observed that papers used 'soundscape data' to describe recordings of sounds occurring in real-world environments, *e.g.*, in a subtropical forest [152]. Furthermore, tools have been developed to represent this data visually as a map [265] or in a colour-coded spectogram [55]. Where Vongkunkij et al. [265] are concerned with representing data directly as captured, Dema et al. [55] enable communities to engage with a mix of local bird call audio recordings.

4.2 Documenting Acoustic Environment Characteristics

When designing soundscapes, it is argued by Schafer that designers should engage with the real-world acoustic environments in which the intervention will take place [229]. Therefore, we also observe the methods that authors use to document the characteristics of the environments they design for. We found 19 papers (8.1% of the analysed papers) in which methods for documenting an existing acoustic environment were utilised. Not surprisingly, except for one paper, these papers included a conceptualisation of soundscapes as acoustic environments. 14 of the papers described the use of audio recordings to document the environment. Three papers included asking participants to observe their environment to later reflect on it. One paper included interviews where participants were asked to reflect on sound experiences but with no active listening exercise included in the study. As exemplified by Lewis and Stasiulyte [169] who conducted binaural recordings, audio recording technologies for documenting acoustic environments now include further options for documenting spatial characteristics.

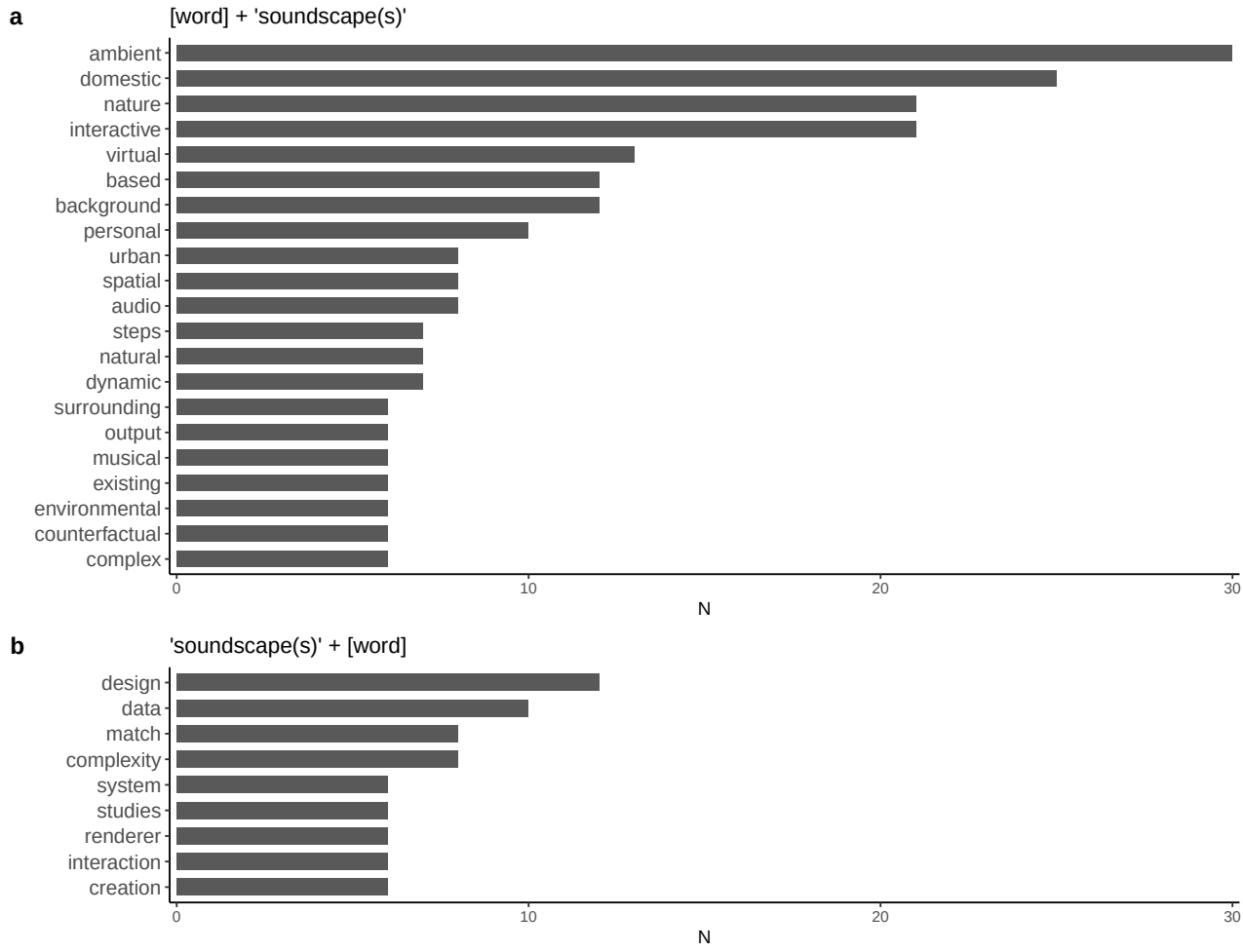

Figure 2: Most common bigrams including the word 'soundscape(s)' in the corpus. A. shows words preceding 'soundscape(s)' (*e.g.*, interactive soundscape). B. shows words following 'soundscape(s)' (*e.g.*, soundscape design).

Looking at the chronological order of these papers, the earliest papers are mostly utilising qualitative methods such as soundwalks and interviews whereas the latest half is almost exclusively utilising audio recordings. To complement audio recordings, four papers describe the use of annotations or text descriptions in the form of diaries.

4.3 Availability of Supplementary Material

Due to the audio-focused nature of soundscape research, supplementary material that goes beyond a textual description of the audio material is often highly helpful. We found that 62 papers (26.4% of the analysed papers) include a video in which the studied soundscape is presented. These videos are most often included as supplementary material on the ACM Digital Library (51 papers), but also include links to YouTube, Vimeo, as well as other sources.

The second most common resource included in the studied research papers is pointing to a project website, as found in a total of 32 papers (13.6% of the analysed papers). Web pages allow researchers to provide additional information, updates to a project following the paper's publication, or videos, among other materials, to interested readers. We identified that 16 of the papers with a link to an external website contain at least one broken link – with important information lost to future readers.

In line with the recent call for open sharing of research artifacts [43, 270], we assessed the practice of sharing research materials in our analysed corpus. In the analysed corpus, the sharing of artefacts to replicate studies, preregistration, or data files is infrequent. Here, we highlight a number of papers that stood out from the corpus in terms of resource sharing. Wolf et al. provide the audio files used in their study as well as an in-depth description of their dataset and method, both as supplementary materials on the ACM Digital Library (ACM DL) and their institution's repository [283]. Gonçalves et al. share a video trailer of their game and details of their online questionnaire, as well as a thematic analysis codebook and presented themes [92]. This paper is the

only paper in our corpus that provides these files on the OSF[2]. Biggs et al. and Heller & Schöning provide the audio files used in their study [14, 107]. None of the analysed papers reports a pre-registration of their work, a practice of registering hypotheses and planned analyses prior to data collection. Proponents argue that through pre-registration, problematic but widespread practices in data analysis (*e.g.*, *p*-value hacking, hypothesising after the results are known) can be diminished [198]. As such, pre-registration might be of value to the soundscape research community.

5 DISCUSSION

5.1 Anchoring Soundscape Research on Common Ground

From our findings, a consensus seems to exist between one of two broad conceptualisations of soundscape: soundscape as acoustic environment and soundscape as composition. In this paper, we propose that researchers investigating or designing soundscapes include a position on soundscape theory – stipulating the conceptualisation of soundscape taken up in their work. This not only benefits the positioning of soundscape research at the level of individual studies against other research, but will support a broader qualification of the research community and help to further carve out the spaces in which we might conduct new studies.

Oulasvirta and Hornbæk recently argued theory has a generative role in design research, meaning that it should push researchers to develop novel ideas and make decisions based on thinking 'what ought' [204]. The importance of bridging theory and practice has also been underlined in articulating new design opportunities and making research advancements [48]. Based on this, we propose an initial description of these spaces, presented in Table 3 as 'conceptualisations', to assist further research in soundscapes within HCI. We believe that such a foundation will enable researchers to see the 'bigger picture' of individual research contributions. This bigger picture is not currently possible to identify. In this section, we present a first step towards defining common ground for soundscape research in HCI based on the conceptualisations of soundscape derived from our analysis: acoustic environment and composition. We also include considerations on potential hybrid approaches. We describe how these conceptualisations can be further grounded in existing research on soundscape beyond the analysed SIGCHI conferences. With this distinction, we extend the research by Brown et al. [25] whose definition, while offering further precision, is not rooted in a particular discipline. We do so with the four aspects presented in the columns of Table 3 and including the perspective of soundscape as compositions.

5.1.1 Designing for real-world or simulated soundscapes. Within this conceptualisation, soundscapes are viewed as perceptual constructs that emerge when a listener hears sounds from a physical environment. It is not merely the physical act of hearing itself but rather the experience of all sounds in combination with each other. Therefore, it is key to this view that soundscapes mediate user-environment relations, thereby emphasising both individual experiences and the context of those experiences. As such, this conceptualisation of soundscape can be compared to Truax' [255] descriptions of user-sound-environment relationships. In addition to this, a key phenomenon is embodiment, as is also essential for sonic interaction design [81], which emphasises that a listener is physically situated in an environment and that a soundscape can be felt and otherwise experienced with one's entire body rather than just through hearing. Typically, methods for documenting experiences of acoustic environments are utilised. These include interviews, diaries, and soundwalks. Of types of environments, our analysis of co-words indicates that domestic and urban environments are commonly used phrases. This suggests that there is an understanding of the characteristics of those environments and points to the potential of defining other types of environment soundscapes.

To further ground this conceptualisation of soundscape, we describe an exemplar study from the included papers in the review. Oleksik et al. [201] presented a study on understanding and designing for improvements of domestic soundscapes. The study included interviews and sound recordings from seven households to first understand the soundscape and subsequently define roles for technological interventions. Following this approach to particularly focus on soundscape rather than sound could enrich current HCI research streams such as ubiquitous computing. To take one example, an early paper by Ishii et al. [128] included in our analysis describes an 'ambientROOM' in which natural soundscapes are used for informational purposes. Our findings point to the potential for supporting and further developing such soundscapes by, *e.g.*, investigating the current soundscape and utilising participatory methods [30]. In order to use this potential, a grounding in common conceptualisations of soundscapes is highly beneficial.

5.1.2 Composing soundscapes of real-world or digital sounds. Within this conceptualisation, soundscapes are viewed as a collection of sounds that are organised in an intentional way and played to listeners. Key phenomena typically include a mapping between an input, *e.g.*, allowing a listener to alter the mix of sounds or determine when it is activated. The end goal is an auditory experience which either supports a primary activity or is the primary activity itself. To create such experiences, authors rely on recordings which are organised intentionally. Several papers present a physical interface for users to interact with the soundscape composition.

For grounding this conceptualisation of soundscape, we point to an exemplar study by Hendriks et al. [109]. This paper describes a handheld tangible cushion interface covered in wool designed for remote co-experiences. The design process was highly influenced by the concept of somaesthetic appreciation, emphasising the relation between users' bodies and the cushions. Moving the cushions triggers and modifies a soundscape consisting of recordings of fire, water, and singing bowls; one cushion triggers fire sounds, and the other triggers water sounds. When these sounds are mirrored between the pair, users who are physically distant from each other can experience a form of intimate communication. The soundscape provided users with a shared sense of context which was further prompted by the possibility of modifying it continuously. Our main takeaway for this conceptualisation is that there is unused potential in differing between soundscapes and other types of sound compositions. Such a grounding will shift the focus to key phenomena and

[2]OSF is a platform for sharing research data with a strong focus on reproducability and long-term availability (www.osf.io).

Table 3: Overview of key conceptualisations of soundscape in HCI as derived from our review. The columns sum up the view of what a soundscape is, key phenomena this view centres around, the intended end goals of studies operating with this view, and what supporting methods are utilised to do so.

Conceptualisation	View	Key phenomena	End goal	Methods
Acoustic environment	A perceptual construct of an acoustic environment.	Mediation of user-environment relation; context.	Improve environment; information distribution.	Interviews; diaries; soundwalks; recordings to support listening.
Composition	Collection of sounds played together in different mixes.	Mapping between input and sound; ambience; atmosphere.	Creating either a supporting background composition to an activity or an auditory experience in itself.	Recordings for playback; organisation of sounds; physical design.

methods beneficial to soundscape research. Finally, this also points to a potential for utilising participatory methods such as those presented by Caramiaoux et al. [30] to engage people in soundscape mapping and design as opposed to individual sounds.

5.1.3 Hybrid approaches. While our analysis is based on the categorisation of papers into one of the two conceptualisations of soundscape (*i.e.*, 'acoustic environment' and 'compositions'), a hybrid approach in which researchers focus both on creating an acoustic environment and design soundscape compositions as interventions into that environment can also exist. Such a hybrid approach can be traced back to Schafer's [229] definition, which included both perspectives. Between the two conceptualisations of soundscape, overlaps exist between the aspects presented in Table 3.

In terms of overlaps in the key phenomena, an embodied approach traverses both conceptualisations. For compositions, this can be seen in the form of physical prototypes handled by users to produce or trigger soundscapes. This can be related to Monache et al.'s [51] discourse analysis on sound-driven design as "[...] inherently embodied, situated, and participatory".

Finally, the conceptualisations can overlap in methodologies, *e.g.*, listening as an essential element for conducting studies. For acoustic environments, this often entails listening to an already existing environment; whereas for compositions listening can be included when searching for sounds to include as well as in organising the design of a soundscape. As such, the two presented conceptualisations do not necessarily exclude each other but can be complementary.

Hybrid approaches can also be identified from our analysis of bigrams including the word 'soundscape'. Ambient was a prevalent co-word that traversed across both conceptualisations. As such, we see potential for future research to explore this hybrid approach. Such investigations have also emerged from soundscape research outside of HCI. Westerkamp, who also collaborated on the WSP in the 1970s, has stated that the term soundscape compositions should not be used "[...] just because it uses environmental sounds as its source material" [276]. She argues that it is instead the link between compositions and acoustic ecology (the study of the connected relationship between sound, society, and nature) that defines the difference between soundscape compositions and other musical compositions. As such, from Westerkamp's point of view, soundscape compositions should be anchored in the place and environment in which they are listened to. This supports our analysis and points to concrete recommendations for future soundscape research in HCI, which we outline in detail below.

5.2 Recommendations for Future Soundscape Research

Based on our review of the literature, we identify a number of gaps and best-practices in prior and current soundscape research. Here, we outline recommendations for researchers incorporating soundscapes in the reporting of their studies in order to increase clarity and transparency, as well as to support emerging agendas in the research community.

(1) Ground soundscape-driven research in a relevant definition. There is a general tendency among the analysed papers to use 'soundscape' as a term for either an acoustic environment or a composition of several audio layers. Both conceptualisations of soundscape take the perspective of audio as a sonic counterpart to visual landscapes. While this perspective can be a helpful metaphor for describing the distribution of audio sources in a physical or digital space, it is often limited and easily confused with other ways of including audio in digital experiences and devices. Further, it excludes the multidisciplinary nature of soundscapes, covering the human experience of the acoustic environment more widely than including individual audio files in a study design. By introducing ambiguity in defining the use of the term soundscape, researchers potentially exclude valuable insights and research directions. Making the definition on which the work is grounded explicit to the reader will help position the intended contribution.

(2) Describe the characteristics of the environment. Within HCI, as well as many other human-focused research fields, there exists a widely embraced practice of reporting basic demographic information on the participant sample (*e.g.*, gender or age distribution). This information provides readers with valuable information for interpreting the findings of a study, and therefore plays an essential role in communicating research findings. Similar to participant demographics, the characteristics of a study environment

significantly affect the results of a study. Within soundscape research, however, we found that authors often rely on imprecise descriptions of both the environment and the intended soundscape (see Section 4.2). Reporting the characteristics of the environment establishes a common foundation for researchers and designers, which can be further utilised in investigating listeners' experiences. McGregor et al. discuss the importance of comparing designers' and listeners' experiences of sound [184]. By describing the characteristics of the environment in which the study was conducted, researchers can more easily put any reported findings into perspective.

(3) Engage with the existing environment. Only 8.1% of the analysed papers included descriptions of how authors engaged with the existing environment for which they were designing. Such engagement can be related to both prompting descriptions of prior experiences with sounds and capturing real-time experiences. Previous research by Caramiaoux et al. [30] and Oleksik et al. [200] shows that engaging participants in recalling memories of sounds can be a highly beneficial approach to designing richer interactions with sound. Furthermore, such an approach should be followed with the aim of engaging users' entire bodies as, elaborated by Franinovic and Serafin [81], listening is an embodied activity that not only involves users' ears.

(4) Include audio or video material to increase understanding and replicability of study results. Many of the studied papers present an audio(visual) system. While the audio often forms an integral part of the study or artwork, the reader is often limited in their interpretation of this material based on textual descriptions alone. For researchers aiming to extend or replicate existing work, audio files are impossible to reproduce based on textual descriptions alone. As such, we urge researchers to include audio or video material with their submission to illuminate the textual description of their soundscape. Selecting a repository with a focus on long-term availability is critical. While we commend Kern et al. for pointing to the sound files used in their project [147], the introduction of link rot has already made some of these unavailable. Dellavalle et al. highlighted this issue of 'link rot' in 2003 [50]. They urged publishers, authors, and libraries to "*adopt better Internet reference policies and archiving strategies to limit the loss of Internet reference information in current medical and scientific literature*" [50]. The ACM DL, YouTube, and Vimeo were the most common repositories among the studies that included audio or video material. Given the ACM DL's commitment to long-term availability and the direct link with the published work, we urge authors to at least include their materials here.

(5) Share research data publicly. Building on the recommendation above, as well as prior work in the broader HCI community [43, 270], we argue for more public sharing of research results. This includes (anonymised) data from participants, but can also consist of other data that is generated during the study (*e.g.*, audio files generated through a design session). The current lack of sharing research data and study materials hampers the replicability of soundscape research. Similar to the sharing of audio or video material, the choice of repository is key to ensuring the availability of presented files. Platforms such as the OSF[2] and the aforementioned ACM DL provide a reliable solution for these efforts.

5.3 Limitations

We identify several limitations in our work that are important to consider when interpreting our results. First, as with any literature review, we were unable to include all relevant material on the chosen topic. We limited the scope of our search to only include papers from SIGCHI sponsored or co-sponsored conferences. While this means that we excluded a number of audio–heavy venues from our investigation, *e.g.*, Audio Mostly which is a SIGCHI in-cooperation conference, we argue that our selection of venues (23 conferences) provides a good overview of the breadth of HCI research in this domain while simultaneously including the most high-impact HCI venues. This also ensures consistency in including and excluding conferences. Future research could expand on this by including specialised conferences as well as journal papers. Second, our discussion of the related work is limited to a high-level overview of sound design in HCI and the study and use of soundscapes beyond HCI research and practice. While this intentionally omits a large number of sound(scape)-related research, we consider these works to be of lesser relevance to our contribution of characterising soundscape research in HCI. Third, our search process only includes papers in which the term 'soundscape' is used, potentially excluding papers where authors use other words to describe similar concepts. Future research could expand on our findings by reviewing similar and related concepts. Finally, we note that the categorisations presented in this work concerning soundscape conceptualisations (see Table 3) are the result of our interpretation of the assessed studies. By abstracting these studies into the presented categories, we encountered a few studies that showed overlap between their content and our chosen categories. While we systematically categorised these papers based on their most prominent contribution and do not believe that these small number of occurrences would change the outcome of our analysis, it is essential to recognise the limitations that inevitably arise when categorising complex research designs.

6 CONCLUSION

In this paper, we set out to characterise and classify HCI-driven soundscape research. Through a systematic review of the literature, totalling 416 articles across 23 SIGCHI conferences, we identified 235 relevant articles that we assessed in depth. Through our analysis, we find that soundscape-related research often lacks a clear definition of soundscape. This lack of definitions highlights a potential for further grounding this research in common conceptualisations. We furthermore highlight that the studied papers can be roughly categorised in one of two conceptualisations on soundscapes: soundscapes as an acoustic environment and soundscapes as compositions. Subsequently, we assessed how studies documented acoustic environment characteristics and how researchers report on the availability of important research materials. For both of these cases, we find that researchers share insufficient information for other researchers to extend or replicate the work presented. Based on these analyses, we present five recommendations for future soundscape research. We hope that our characterisation of current soundscape research in HCI presents an overview of this increasingly relevant theme within HCI research and will result in greater overall clarity, transparency, and replicability of future soundscape research.

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OVERVIEW TABLE

Table 4: Overview of analysed papers.

				Acoustic Env.			Compositions				
Ref	**Year**	**Conf.**	**Definition**	**Real-world**	**VR or AR**	**Simulated with speakers**	**Musical or ambient**	**Mix of real-world**	**Mix of real-world and digital**	**Env. Documen.**	**Resources**
[208]	1997	CHI					✔				
[210]	1997	CHI		✔							
[153]	1997	CHI				✔					
[128]	1998	CHI				✔					🎞
[281]	1998	CHI		✔							
[161]	1999	CHI					✔				
[19]	2000	CHI					✔				
[94]	2000	CHI									
[275]	2000	CHI					✔				
[11]	2001	CHI					✔				🎞
[218]	2002	CHI			✔						
[235]	2002	DIS					✔				
[78]	2002	ICMI				✔					
[206]	2002	ICMI							✔		
[21]	2003	CHI					✔				
[278]	2003	IDC	Own + Source		✔						
[82]	2004	DIS					✔				🔗
[140]	2004	DIS					✔				🔗
[179]	2004	IDC			✔						
[250]	2004	IUI			✔						
[273]	2005	C&C	Own						✔		
[279]	2005	CHI	Own						✔		
[142]	2005	CHI					✔				
[28]	2005	IUI	Own				✔				
[118]	2006	CHI					✔				
[63]	2006	CHI	Own + Source				✔				
[115]	2006	CHI			✔						🔗
[271]	2006	DIS					✔				
[105]	2006	MobileHCI		✔							
[232]	2007	C&C	Own	✔							
[113]	2007	ICMI					✔				🔗
[75]	2007	MobileHCI			✔						
[241]	2007	MobileHCI			✔						
[60]	2007	TEI	Own + Source	✔							
[201]	2008	CHI	Own + Source	✔						✔	
[209]	2008	DIS	Source	✔						✔	
[230]	2008	IDC					✔				
[131]	2008	IUI							✔		
[152]	2009	CHI		✔						✔	🔗
[106]	2009	CHI			✔						
[114]	2009	ICMI			✔						
[102]	2009	IDC					✔				🔗
[101]	2009	TEI					✔				🔗
[17]	2010	DIS					✔				🔗
[173]	2010	DIS					✔				
[237]	2010	VRST			✔						
[246]	2011	C&C					✔				
[249]	2011	CHI					✔				🎞
[196]	2011	CHI			✔						
[108]	2011	TEI		✔						✔	
[90]	2011	TEI					✔				
[183]	2012	CHI			✔						
[112]	2012	CHI					✔				🎞
[217]	2012	DIS				✔					
[264]	2012	DIS					✔				🔗
[225]	2012	DIS			✔						
[171]	2012	DIS					✔				
[155]	2012	MobileHCI			✔						
[52]	2012	TEI					✔				🔗🎞
[13]	2012	TEI					✔				🎞
[162]	2013	C&C					✔				

Table 4: Overview of analysed papers. *(continued)*

				Acoustic Env.			Compositions				
Ref	**Year**	**Conf.**	**Definition**	**Real-world**	**VR or AR**	**Simulated with speakers**	**Musical or ambient**	**Mix of real-world**	**Mix of real-world and digital**	**Env. Documen.**	**Resources**
[263]	2013	CHI					✔				
[124]	2013	CHI					✔				
[168]	2013	CHI		✔						✔	
[12]	2013	TEI					✔				
[219]	2013	TEI					✔				
[226]	2013	TEI							✔		
[125]	2013	TEI					✔				
[58]	2013	TEI					✔				
[267]	2014	CHI	Own				✔				
[185]	2014	CHI Play	Own + Source						✔		
[84]	2014	DIS									
[74]	2014	DIS					✔				
[68]	2014	IDC					✔				
[72]	2014	TEI		✔							
[248]	2015	C&C					✔				
[35]	2015	C&C					✔				
[34]	2015	C&C					✔				
[66]	2015	CHI					✔				
[9]	2015	CHI							✔		
[111]	2015	EICS									
[288]	2015	HRI					✔				
[148]	2015	HRI			✔						
[212]	2015	IDC					✔				
[283]	2015	IUI	Own	✔							
[174]	2015	MobileHCI					✔				
[251]	2015	MobileHCI					✔				
[215]	2015	TEI		✔							
[122]	2015	TEI	Source				✔				
[233]	2015	TEI					✔				
[165]	2016	AutoUI	Own				✔				
[136]	2016	AutoUI					✔				
[268]	2016	CHI					✔				
[67]	2016	CHI					✔				
[126]	2016	CHI									
[213]	2016	CHI					✔				
[257]	2016	CHI					✔				
[284]	2016	DIS					✔				
[38]	2016	DIS					✔				
[287]	2016	DIS					✔				
[10]	2016	DIS					✔				
[202]	2016	DIS					✔				
[77]	2016	ICMI		✔							
[44]	2016	ICMI					✔				
[194]	2016	ISS	Own				✔				
[33]	2016	MobileHCI	Own	✔						✔	
[182]	2016	MobileHCI		✔							
[189]	2016	TEI			✔						
[147]	2016	VRST			✔						
[135]	2017	AutoUI					✔				
[266]	2017	C&C				✔					
[240]	2017	C&C			✔						
[47]	2017	C&C	Own				✔				
[207]	2017	C&C					✔				
[36]	2017	CHI				✔					
[151]	2017	CHI				✔					
[4]	2017	CHI	Own			✔					
[138]	2017	CHI			✔						
[197]	2017	CHI					✔				
[145]	2017	CHI Play					✔				
[258]	2017	CHI Play					✔				
[221]	2017	CHI Play			✔						
[280]	2017	DIS									
[177]	2017	DIS					✔				

Table 4: Overview of analysed papers. *(continued)*

				Acoustic Env.			Compositions				
Ref	**Year**	**Conf.**	**Definition**	**Real-world**	**VR or AR**	**Simulated with speakers**	**Musical or ambient**	**Mix of real-world**	**Mix of real-world and digital**	**Env. Documen.**	**Resources**
[121]	2017	DIS			✔						
[227]	2017	IUI							✔		🎞
[130]	2017	TEI					✔				
[32]	2017	UIST			✔						🎞
[1]	2017	VRST				✔					🎞 </>
[247]	2018	CHI					✔				
[71]	2018	CHI									
[18]	2018	CHI		✔							🎞 🔗
[89]	2018	CHI				✔					🎞
[186]	2018	CHI	Own	✔							
[239]	2018	CHI				✔					
[195]	2018	CHI Play									
[170]	2018	CHI Play					✔				
[234]	2018	DIS					✔				
[203]	2018	DIS		✔							
[16]	2018	DIS				✔					
[37]	2018	DIS	Own		✔						
[228]	2018	IDC		✔						✔	
[45]	2018	IDC	Own								
[172]	2018	IDC					✔				
[150]	2018	MobileHCI	Own			✔					
[190]	2018	MobileHCI					✔				
[104]	2018	TEI			✔						🎞
[5]	2018	TEI	Own				✔				
[238]	2018	TEI					✔				
[220]	2018	TEI									
[269]	2018	TEI					✔				
[137]	2018	Ubicomp		✔							
[265]	2018	Ubicomp	Own + Source	✔							🎞
[253]	2018	Ubicomp	Own + Source	✔							
[166]	2018	UIST	Own		✔						🎞
[244]	2018	UIST	Own				✔				🎞
[242]	2018	UIST	Own + Source	✔							
[29]	2018	UIST	Own						✔		🎞
[157]	2018	UMAP	Own	✔							
[117]	2019	CHI				✔					🎞
[83]	2019	CHI									
[31]	2019	CHI		✔						✔	🎞
[187]	2019	CHI	Own				✔				🎞
[55]	2019	CHI	Own				✔				
[42]	2019	CHI	Own				✔				
[8]	2019	CHI	Own								
[156]	2019	CHI		✔							🎞
[3]	2019	CHI		✔							
[158]	2019	CHI	Own				✔				
[259]	2019	CHI Play	Own		✔						🎞
[274]	2019	CHI Play	Own								🎞
[119]	2019	DIS	Own + Source			✔					
[73]	2019	DIS	Own			✔					
[139]	2019	DIS	Source	✔						✔	
[98]	2019	DIS	Own				✔				
[57]	2019	DIS		✔						✔	
[46]	2019	IDC				✔					
[133]	2019	IUI	Own		✔						
[123]	2019	MobileHCI	Own			✔					
[256]	2019	TEI	Own				✔				
[214]	2019	TEI	Own		✔						🎞 🔗
[236]	2019	TEI									
[97]	2019	TEI		✔						✔	🎞
[80]	2019	TEI					✔				🎞
[285]	2019	Ubicomp			✔						
[93]	2020	CHI	Own	✔							</>
[120]	2020	CHI	Source			✔					
[262]	2020	CHI		✔							

Table 4: Overview of analysed papers. *(continued)*

				Acoustic Env.			Compositions				
Ref	**Year**	**Conf.**	**Definition**	**Real-world**	**VR or AR**	**Simulated with speakers**	**Musical or ambient**	**Mix of real-world**	**Mix of real-world and digital**	**Env. Documen.**	**Resources**
[2]	2020	CHI					✔				🎞
[180]	2020	CHI	Own		✔						🎞
[54]	2020	CHI		✔						✔	🎞
[199]	2020	CHI			✔					✔	
[143]	2020	DIS		✔						✔	
[100]	2020	DIS	Own + Source	✔						✔	
[286]	2020	DIS		✔							
[243]	2020	DIS					✔				🎞
[88]	2020	DIS		✔						✔	
[110]	2020	DIS		✔							
[64]	2020	DIS		✔							
[24]	2020	DIS	Own				✔				🎞 🔗
[39]	2020	DIS					✔				🎞
[163]	2020	HRI					✔				🎞
[193]	2020	ICMI			✔						
[188]	2020	IDC		✔							
[216]	2020	IDC					✔				
[181]	2020	IMX			✔						🎞
[191]	2020	IMX			✔						
[99]	2020	MobileHCI		✔							
[175]	2020	MobileHCI					✔				🎞
[79]	2020	TEI					✔				
[127]	2020	TEI					✔				
[169]	2020	TEI	Source	✔						✔	🔗 🔗
[70]	2020	TEI					✔				
[85]	2021	C&C			✔						
[224]	2021	C&C		✔							
[56]	2021	C&C							✔		
[23]	2021	CHI					✔				🎞 🔗
[261]	2021	CHI	Own		✔						
[109]	2021	CHI					✔				
[49]	2021	CHI					✔				
[116]	2021	CHI			✔					✔	🎞
[14]	2021	CHI					✔			✔	</>
[160]	2021	CHI					✔				🎞
[92]	2021	CHI			✔						🎞 </>
[20]	2021	DIS					✔				
[65]	2021	DIS			✔						
[222]	2021	HRI		✔							🎞 </>
[178]	2021	HRI		✔							
[103]	2021	TEI					✔				🎞
[41]	2021	TEI					✔				
[91]	2021	TEI				✔					🎞 🔗
[245]	2021	TEI					✔				🎞
[95]	2021	TEI					✔				
[159]	2021	TEI	Own								🎞 🔗
[260]	2021	TEI	Own								🎞 🔗

Legend:
🔗: Project website
🔗: Broken link
🎞: Project video (ACM DL, YouTube, Vimeo)
🔊: Audio files provided
</>: Study replication files