Celebrating 20 Years of Computer-based Audio Gaming

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ABSTRACT

We look back on two decades of academic research on audio games. During this time, a substantial amount of research has explored many facets of this special genre of computer games. However, despite many publications, there is a lack of review papers, which help delineate this growing research field. For this reason, we take one step back and investigate 20 years of audio game research by synthesizing a literature review adopting grounded theory methods. The resulting research map provides an overview of efforts into audio games with a special focus on *how to design for audio games*. We observed three important trends or tensions in audio game research. Firstly, audio games research depended heavily on technological advancements during the last two decades. Secondly, most studies about audio games were conducted with novices to audio games in lab situations, that is, based on artificial situations and *not* on *real* gamers and their genuine experience. Thirdly, the audio game design process *per se* has been greatly neglected in the literature so far. We conclude the paper by discussing design or research implications.

CCS CONCEPTS

• **Applied computing** → **Computer games**; • **Human-centered computing** → *HCI design and evaluation methods*; *User studies*; • **Software and its engineering** → Designing software.

KEYWORDS

audio games, review, game design, grounded theory methods

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1 INTRODUCTION

It has been 20 years since Lumbreras and Sánchez published a fundamental paper [27] that introduced audio games to academia. This work inspired and motivated researchers of several disciplines – most notably Human-Computer Interaction (HCI), interaction- and game design – to focus on this genre. It is regarded as a highly relevant field of research, because it has the potential to provide sighted and blind people alike with playful activities and user experiences. Despite a strongly growing body of work, there is however a lack of review papers that synthesize the findings of these efforts (with some exceptions with a very specific focus, e.g. on cognition in audio games [11]). It is timely to reflect on these 20 years of audio game research in form of a review paper, providing an overview of the last two decades of audio games. We do so by drawing on Grounded Theory Methods (GTM) [10, 21, 45, 55] and map out the landscape of audio game research with a special focus on *how to design for audio games*. As we will show in later sections, we found that it was primarily organized around four main themes (see Fig. 1). In addition, we observed three important trends or tensions in audio game research: the role of technological advancements, the predominance of lab studies with novices, and the neglection of the audio game design process *per se*.

Our literature review is offered as general guidance to designers (and other interested people), who wish to obtain an overview of the research efforts into audio games of the last 20 years. It is not a specific review of a clear-cut topic such as "sonification techniques for audio games" or "audio games as serious games" that seeks to collate most comprehensive information on that particular topic. Rather, the present literature review celebrates the last two decades of research activities by highlighting important themes, trends, and productive tensions when it comes to *designing for* audio games.

What are Audio Games?

Audio games are computer games that use sound as the main feedback modality for the players. They can be supplemented by visuals but those visuals are not required to successfully/joyfully play these kind of games. Usually, audio games are played with headphones and keyboard, however, the rise of mobile devices in everyday life brought audio games to mobile too, where the inputs are usually touch-based gestures on a screen. Commercial and free-ware audio games span a wide range of game genres similar to video games, which makes them attractive to people with different game preferences. The main target group of audio games are visually impaired people, however, the trend in creating games that are universally accessible by everyone is an increasingly consensual choice for audio game design in the audio game design community. One of the most active communities, audiogames.net, provides a list of available audio games, general information about audio games, and a forum that has an active and supportive community. With the growing popularity of audio games (which is by no means comparable to the success of video games, though), there was also a strong increase in published research papers about this subject. The contribution of the paper on hand – as mentioned above – is to provide a review of that literature with a focus on implications for *designing for audio games*.

2 RESEARCH APPROACH AND METHODS

We created the present review to provide designers and researchers with an overview of the aspiring academic field of audio games. It is targeted at people, who are in a similar situation as us, namely, in search for a broad map of audio games that provides guidance in navigating the research efforts and trends of the past 20 years. Our goal is neither to paint a complete picture (i.e., create a list containing 'everything') nor to provide a detailed view on one particular aspect of audio games (e.g. how sonification can be implemented). Instead, we identified the most prominent themes or research strands in *designing for audio games* (see Discussion for implications and limits).

To this end, we employed GTM [10, 21, 45] for creating the literature review as proposed by Wolfswinkel et al. [55] and originally based on a guideline by Webster and Watson [51]. By following this approach, we built a theory (i.e., a set of emerged themes) based on published papers in a concept-centric way. In more detail, Wolfswinkel et al. [55] proposed a five-stage process for reviewing, which they recommend to revisit and to refine in the course of creating the review. The five proposed stages are *Define*, *Search*, *Select*, *Analyze*, and *Present*. We will briefly describe the stages in each respective subsection, including the decisions we made throughout the process.

Database	*Total Results*	*Limited to*	*Date retrieved*
ACM	69.140	Top 200	02.05.19
IEEE	8.703	Top 200	03.05.19
Springer	42.312	Top 200	05.05.19
Google	*not stated*	Top 200	07.05.19

Table 1: Number of results for our search term.

Define and Search

We focused on published papers about the design and evaluation of audio games during the last 20 years, when this research began. We were primarily interested in research published in the field of HCI, and were less interested in purely technical papers, for example, about how to engineer better headphones, *etc.* Accordingly, we used the most important/comprehensive databases for HCI and related work – ACM Digital Library, IEEE Xplore, and Springer Link, complemented by systematic queries on Google Scholar – to search for and retrieve literature.

The selection of the search terms is tricky when looking for "audio games" related literature. Audio games go under many names, and searching for this term alone would miss a large fraction of the work. In addition, "audio" and "games" as standalone terms return a huge set of matches, since papers about audio and/or games are common. Moreover, search engines may ignore the order of the terms, which results in a data set about audio *in* games. We considered these difficulties in an iterative process with test queries and adjustments. Eventually, we conducted our search based on the following search string:

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(audio-only) OR ("audio game*") OR ("audiogame*")
    OR (audio-mostly) OR ("game*" AND (non-sighted
     OR "visually impaired" OR sound-based OR
    blind))
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We excluded short papers or notes and put the main focus on full papers, a common practice in literature reviews (e.g. [11]). Table 1 shows the number of papers that resulted from our query with the search term from above.

Select and Analyze

The number of papers in Table 1 seems astonishingly high. However, these search results are ordered by relevance by each database. After manual inspection, we found that papers beyond position 200 had virtually no relevance for audio games. Therefore, we limited the results to the top-200 papers for each database and ignored all papers at a higher position. Next, we used a script to copy the titles and abstracts of these top-200 articles into an *EXCEL* sheet, removed the duplicates, and split this list between the authors of this review for another manual inspection. In this way, we were

able to remove additional and plenty of *false positives* and other inappropriate papers. As a next step, we removed all papers that were not concerned with the design of audio games, since in this review, we were interested in practical implications for *designing* audio games. This procedure led to a remaining pool of 128 papers that seemed relevant for further analysis.

This was the step were GTM came into play. Using *Word* tables and *Weft QDA*[14], and analogous tools like post-its or paper memos, we applied *open coding*, that is, we assigned codes (e.g., *user study*, *sonification*, *inclusive design*, ...) to the 128 papers by first of all reading the abstracts. Whenever the abstracts were unclear or they hinted at additional interesting ideas inside the paper, we too opened the main body of the text and assigned codes. In this way, we iteratively created a set of codes, which we then used for *selective coding*, that is, the elaboration of higher-level themes that organized the *open codes* from the previous phase into important concepts in audio game research. The final main themes correspond to the primary research strands or topics in audio game research as presented in the next section. During this analysis, we read 48 papers in great detail, because we identified them as seminal publications about audio games. We will refer to them during the presentation of the audio game landscape as exemplary landmark papers.

3 20 YEARS OF RESEARCH INTO AUDIO GAMES

Over the years, an exciting body of literature about audio games has been assembled. In the following, we offer salient concepts or themes that emerged from our GTM analysis. Here, our focus was on broader implications for *designing* audio games. Accordingly, the themes center around *crafting* audio games, *the people involved and evaluation*, *technological trends*, and common *technological input-/ output modalities*.

Crafting the Audio Game Experience

Special Purpose Tools. Several tools that support audio game designers, developers and researchers in producing audio games have been created during the last 20 years. These tools can be divided into node-based tools [4, 39, 43], map makers [28, 29], game/level editors [6], code-based tools (software frameworks) [23], full game engines [2, 49], or software that is usually used in audio-only disciplines (e.g. Max/MSP in audio engineering [46]). Some tools were designed for visually impaired users, too [4]. What these tools have in common is their motivation to empower gamers, designers and developers to implement their ideas of audio games. Some promising tools have been published in papers that haven't been made available to the public [34] or that weren't at time of the respective publication completed yet [37].

While such tools are powerful and inspiring, there is nevertheless consensus in the literature that great tools do not necessarily lead to great games. To this end, researchers also conducted valuable research into *how* to design audio games during the last two decades, as reported next.

Figure 1: Primary themes as emerged from our literature analysis.

Guiding Design. There have been several attempts to formalize audio game design by means of guidelines or recommendations for audio game design. Collections of game accessibility guidelines [59] provide (beginner) designers with ideas and inspirations on how to design *accessible* games in the context of ability-based design [54] or inclusive design [22]. Somewhat relatedly, researchers call for more sensibility regarding accessibility in *video* games [3] to allow users with special needs to play conventional video games, too.

Furthermore, there are researchers that synthesized their audio game design principles from existing literature [18] to transfer them to a specific field (e.g., education [40]). Then again, researchers focused on 'anti-rules' in order to make audio game designers aware of common pitfalls found in audio game design [47].

Others have provided design lenses or sensitizing concepts, for example, *Hyperstories* as propsed by Sánchez et al. [27, 41] or the *Scary Shadow Syndrome* described by Liljedahl et al. ('a shadow on the wall can be scarier than seeing the actual monster') [26]. Gärdenfors recommended establishing an auditory counterpart to visual iconography, otherwise abstract sounds need explanation before they can be understood by the players [19], which Urbanek et al. confirmed as being problematic in their publication [47].

Reverse-engineering Audio Games ... The identification of elements or characteristics that are typically found in audio games help to describe audio games during game design and game development. Röber and Masuch investigated auditory

elements (e.g. speech), sonification and interaction strategies (including interactables like obstacles) [37]. Friberg and Gärdenfors looked at a variety of audio game prototypes in order to elaborate different sound categories, which they found useful when designing audio games, namely *avatar sounds*, *object sounds*, *character sounds*, *ornamental sounds* and *instructions* [16]. Other authors identified similar sound design principles [26]. The terms *Earcons* and *auditory icons* (i.e., 'audio icons') were prominently used in early audio game design under the influence of the *Auditory Display* community [15, 16, 38, 46].

... Toward 'Genuine' Audio Games. While audio games can be designed by 'translating' or 'adapting' (video) games [5, 15, 19, 22, 42, 46, 58], they can also be conceptualized right from the beginning as 'genuine' audio games [50]. In line with this latter strategy, Velleman et al. explored game design by "[...] using sound as the main fundamental throughout a design process" [50, p.258]. Papworth suggested using "[...] audio as its principle mechanism for driving the gameplay" [34, p.1]. These examples are worth mentioning here, since they are rare exceptions where researchers were actively talking about designing from an *audio-centered* perspective. In this line, Röber and Masuch recommended that design should rather focus on "[...] the benefits of audio-only gaming, than complaining about the difficulties introduced through the non-visual interface" [38, p.94]. Gaudy et al. explored their commitment that "[... an audio] game should be playable as soon as a player has a first contact with it" [20, p.180]. With their exploratory musical maze, they investigated feasibility and provided useful insights for designing audio games to be intuitive.

Missing Meta-Reflections about the Design Process. Only few papers explicate design aims, design solutions, and design decisions made along the process that led to the resulting audio game [34]. Some reflected about their design by documenting design issues in their audio games [13]. Beksa et al. explored the potential of audio game *prototyping* throughout his work on the Audio Game Hub [4, 5], which has been released to several platforms, including iOS, Android and Windows. However, in the largest parts of the literature, design *per se* is more or less conceptualized as a *black box* without informing the reader what actually happened during design work.

User Participation and Evaluation

While some researchers clearly state that audio games should be designed for everyone [38, 48], others say that they explicitly target "[...] blind persons as final users" [12, p.38]. Accordingly, the group of recruited participants for audio game studies is diverse. They range from sighted players and sighted non-players to visually impaired non-players and visually impaired gamers [1] (see the following paragraphs). However, only a minority of researchers actually focus on the needs of *true* audio gamers outside lab situations to understand this genre [1] or for evaluation [3]. Furthermore, researchers that include people, who play computer games in their studies, usually don't state if their participants have also played *audio* games before [31].

Evaluation Techniques. For evaluation, HCI techniques are usually employed. Some researchers describe how they adapted such methods to better match them with audio games. For example, Campos and Oliveira – inspired by Usability heuristics in user interface evaluation – postulated heuristics for audio game evaluations for users who are blind [12]. With this, they sought to contribute a framework for audio game evaluation. In a classic paper, Lumbreras and Sánchez asked participants to rebuild an audio game using LEGO blocks (different blocks represented different elements like obstacles or doors) in order to investigate whether they were able to create a mental map of the scenery [27]. In bad design work, the imagined soundscape/map can be different from the soundscape/map as intended by the designers [26].

Study Design: User Goals vs. Technology Perspective. For evaluation purposes, it is imperative to describe the study, its user goal, and additional contextual information. A typical format for presenting audio games or audio game projects entails a summary of project goals and examples of games that had been developed during the corresponding project [2, 4, 5, 16, 19, 38, 50], as part of third-party projects [29], or that have been created for the commercial market and given to participants [53]. The descriptions of the audio games themselves varied in length, focus and detail (e.g., detailed [56] or rather brief [57]). Another way of presenting audio games is a more technical one, describing the technologies used and their actual implementation [6, 9, 15, 36, 39].

Testing with Sighted People. A strategy for playtesting audio game prototypes is to test them with sighted players first, and then with visually impaired people at a later stage [43] or to acknowledge that these games were made for sighted players [46]. Others specifically designed their games for visually impaired people, but tested them with sighted players only, e.g. [33].

However, some papers reported concerns, that sighted participants (may) struggle in playing audio-only [29, 40]. Therefore, participants were temporarily blinded (by blindfolding them or simulating visual impairment with blurry glasses) [58]. Even though this cannot even simulate nuances of the experiences blind and visually impaired people have, it brought sighted players at least one step closer to a genuine audio-only experience.

Testing with Visually Impaired People. The inclusion of visually impaired people in the whole design or testing process was recommended by some authors [7]. An example for this can be found in [56], where visually impaired participants tested different iterations of an audio game prototype.

Yuan and Folmer [58] and Kim, Lee, and Nam [24] incorporated different user groups based on vision acuity and game experience into their evaluation. Other researchers encouraged letting visually impaired and sighted players compete with each other, for example, as in Drive [50].

Audio gamers who are visually impaired are notably the most appropriate participant group for studies about audio games, as long as its target group is blind people. This is reflected, for example, in [1] by the recruitment of the participants according to their study goals.

For this reason, collaborations between researchers and *Schools for the Blind* [23, 27, 33, 41, 53] or camps for visually impaired people [20] were quite common and proved as a fruitful source for participant recruitment.

Technological Progress and Audio Games

Audio games were traditionally played in front of computers [27]. However, there is a trend in academic research in moving away from classic audio games towards incorporating the players in a more agile way. This trend coincides with the introduction of mobile computers like mobile phones and more powerful laptops. Research prototoypes for audio games increasingly began to 'play' with the users' physical positions or movement, e.g., audio games that incorporate *real walking* or GPS positioning [9, 32, 36, 50]. Such prototypes showed that audio games can be successful in "leaving the screen" [38].

Researchers even began to explore supporting outdoor sports by audio games in a playful way, for example, as investigated in an audio soccer project [44]. Lee and colleagues [25] created an exergame, "Dungeons & Swimmers", to be played during swimming exercises, providing the swimmers an authentic 'dungeon experience'. Swimming is not the only sports context that was explored for exergaming through audio games. Badminton is another example of how audio games can be connected with exergames [24]. In this project, a usual badminton racket was modified with sensor hardware so that the players could play this audio game naturally.

In summary, we can clearly observe how technological progress changed the scope of research projects from desktop audio gaming to experimental explorations in the real world.

Input- and Output Techniques

Audio game research and design in particular has brought up different interfaces for in- and output over the years. Remarkably, new interfaces for games are nothing new, however, additional interfaces for a niche gaming genre with a significant impact on the user experience is indeed notable and thus listed as one of our findings.

Feedback on Different Levels. Audio games are usually played with headphones [38] rather than with speakers to create an auditory space [52]. With headphones, audio games can effectively make use of 3D sound spatialization. Head-tracking headphones [37] or devices [32, 36] are used as well, enhancing the auditive perception by the gamers.

When sound alone does not suffice to make the game accessible for the visually impaired gamer, additional stimuli can be incorporated. For example, the authors of Blind Hero [58] created a glove that offered haptic-feedback, which was equivalent to the visual feedback that Guitar Hero usually provides. Hence, the translation from video to haptics made the game accessible for visually impaired people.

Keyboard is not the Only Input. Different interfaces for input were used over the recent 20 years. Some of them have been designed and built especially for a specific case, a specific study or game [30]. Others have included existing technology to enhance audio gaming [36]. However, even though audio games may motivate researchers to invent new interaction devices, the main input devices for audio games are still either keyboard [13, 20, 26, 27, 37, 39, 53], controllers [1, 16, 30], or touch screen devices [4, 7, 43]. Leap Motion as a hand gesture interaction device has been used in an audio games, as well [57].

In particular, when it comes to exergames, researchers created own input devices for their audio games, e.g. additional sensor hardware attached to a Badminton racket [24] (see previous section on technological progress).

Some audio game papers mentioned a mouse as input device [6, 35], even though a mouse is commonly not used by blind people (for audio gaming), as it is designed for navigating the (2D) visual space.

Mixed Input and Output Devices. Some designers employed a mix of in- and output interfaces to play audio games. As an example, in the *GRAB HAVE* environment by [56], the users could *feel* virtual objects via a haptic interface (output) in addition to auditory information, while by the same means the person could interact (input) with the virtual environment.

With the "The Audio Adventurer", Mendels and Frens [30] built a complete audio game setup, which not only included software but also hardware. The controller was integrated into the game, providing the player an interface for moving in the scene (by rotating one part of the controller) or for scrolling through the player's inventory.

The Interplay between Interface and Design. The design of an audio game can be influenced by the interface the game is played with and vice versa. As an example, in "The Audio

Adventurer", the researchers built a custom controller for traversing the scene [30]. They showed by means of comparison to other controllers, that the feedback of the participants strongly dependent on the properties of the interface. This feedback again can potentially lead to different design decisions in the next design iteration of the prototype.

4 DISCUSSION

We found three observations from our analysis particularly interesting and like to discuss them here, as they should deserve further attention in future research, in our estimation.

Firstly, the trend in using technology in audio games appears to be similar to the technological trend in video games [5, 36, 53]. Starting with the stationary PC, audio games as well as video games have found their way onto mobile devices. In addition to that, audio games *by real walking* can be considered clearly equivalent to location-based video games or video games in Virtual Reality (VR), without the necessity of graphics. However, since an important target group of audio games are visually impaired people and audio games do not rely on visuals, it raises the question of how VR and Augmented Reality might benefit audio games in the future (besides providing the advantage of novel realistic sound libraries from VR). We therefore raise the question, if academic research should focus again on conventional 'desktop' audio games, because important challenges remain to be investigated there (see next).

Secondly, the choice of participants for the evaluation of an artifact – or in this case, a game – has an impact on the validity of the data gathered and therefore the results researchers get. While we are convinced that not every study needs audio *gamers* as participants for evaluation, more studies with (experienced) *gamers* (as opposed to people, who never played audio games before) outside of lab situations might lead to relevant results, as they are the target group for whom these games are actually made (e.g. compare discussions about theoretical sampling [8]).

Thirdly and finally, the nature of audio game *design processes* is under-researched. In video games, on the contrary, the documentation of design processes is common and leads to use-cases everyone can learn from. An illustrative example of how such documentation can be done is demonstrated by Fullerton [17], who collated a collection of interviews and case studies of people from the gaming scene, describing their experiences. Such collections for audio games should be helpful to improve our understanding of the audio game design process, too.

Notes on Grounded Theory and Literature Reviews

Wolfswinkel et al. [55] proposed GTM for creating literature reviews to introduce more rigor to the process, in particular, during the analysis/coding of the selected papers. They refer to classic GTM texts [10, 21, 45], which were motivated by a *positivist* approach to qualitative research, that is, they aimed at discovering unbiased and objective observations in text in analogy to natural scientists and their (quantitative) observations and experiments. This approach to GTM was later challenged or extended, and an increasing number of researchers adopted a *constructivist* version of GTM [8]. They acknowledge that the objectivity in coding/analyzing will always be limited. Rather, such activities are always an *interpretation*. We agree with this argumentation. While we conducted our analysis with great rigor until it was *saturated*, the present research landscape of audio games is also our interpretation. Other researchers might end up with different interpretations or choose different perspectives on that landscape. To put it in the words of Wolfswinkel et al.: "[...] a literature review is indeed never complete [...] a good review must be a richly competent coverage of a well-carved out niche in the literature. Researchers writing a review may even choose to analyze from a particular angle. As long as they explicate this point of view clearly and argue logically, their deliberate incompleteness is not necessarily a problem." [55, p.3].

5 CONCLUSION & FUTURE WORK

We used GTM to synthesize a literature review on audio games to celebrate the past 20 years of academic research since the first fundamental publications (e.g. [27]). The result shows a research landscape around audio games and maps out prevalent research themes with a focus on *designing for* audio games. In addition, we discussed current trends and made suggestions for some spots on the landscape that would be worthwhile for further investigations.

After having provided the present general literature review for orientation in the broad field of audio games, we hope to see further reviews with specific foci to complement our work and to elaborate on more details. For example, overviews on how *accessibility problems* or *game editors* have been explored in the audio game literature.

Concluding, as a final note, we would like to call for a consistent use of 'audio games' as paper keywords to increase traceability and visibility of audio game papers in search engines.

6 ACKNOWLEDGMENTS

Removed for blind review.

APPENDIX

The papers under analysis were retrieved from the following conferences (format: <name> (<amount>), ordered descending: ICCHP (6), ICAD (5), AM (4), CHI (4), ACE (2), ICDVRAT

(2), AES Convention (1), ASSETS (1), CHI Play (1), EuroHaptics (1), Fun and Games (1), GME (1), HCII (1), ICERI (1), IDC (1), ISD (1), IUI (1), MELECON (1), RoCHI (1), UAHCI (1), UbiComp (1). Journals (same format): CPB (1), HCIS (1), IJCGT (1), LNCS (1), NDCR (1), PLoS ONE (1), SoCP (1), UAIS (1), Unknown (1). This list shows that the most important venues for audio games were conferences around *disability* or *sound*. Still, the pool of outlets was diverse, and researchers with many different backgrounds show interest in and investigate audio games.

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