# Unseen: a 3D immersive experience game for visually impaired individuals

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**Abstract.** *The increasing importance of accessibility, particularly in disability rights, is evident. "Unseen" is a prototype with binaural audio technology to create an immersive 3D gaming experience to promote accessibility and digital inclusion. It aims to provide an immersive audiogaming experience for both sighted gamers and visually impaired people. An evaluation of the prototype was conducted to verify users' understanding of audiogame interactions and to determine the effectiveness of the developed mechanisms. Valuable information was collected through laboratory tests that helped identify areas for the game improvement as well as the elements that left users satisfied and motivated. These research results notably exemplify promoting digital accessibility in gaming and engaging individuals with visual impairments in the virtual world.*

## 1. Introduction

Accessibility, a topic that has been increasingly discussed, has gained significant visibility in recent years. Accessibility is closely related to the rights of people with disabilities [Brazil Decree, 2004]. However, in a broader sense, accessibility is the condition that enables the overcoming of obstacles that represent barriers to the active participation of individuals in various aspects of social life.

In this sense, digital inclusion consists of providing all citizens, in an equal manner, with the opportunity to have access to information and communication technologies (ICTs).

Data from IBGE [IBGE, 2010] shows that in Brazil, there are 35,774,392 people with visual impairments experiencing some difficulty, significant difficulty, or total blindness, representing 14.19% of the population. The degrees of visual impairment encompass a wide spectrum of possibilities, ranging from total blindness to perfect and total vision. From here on, the term "visual impairment" refers to the range that encompasses from blindness to subnormal vision (low vision).

In this context, the objective of this paper is to promote the culture of digital accessibility and demonstrate that it is possible to recognize and include people with disabilities within their environments. To achieve this, a prototype called "Unseen" was developed at Lab3D (Virtual Reality Laboratory - http://lab3d.coppe.ufrj.br) of COPPE/UFRJ in Brazil. This serious game is used in an educational context and primarily targets individuals with visual impairments.

The 3D world is primarily visual, and access to this type of content is highly limited for visually impaired individuals. However, with the use of a technological feature called

binaural audio, it is possible to enable their participation, making the experience similar to that of a sighted user. In this sense, a digital game that can be enjoyed by both visually impaired and sighted individuals, using three-dimensional (3D) sound as the main form of feedback, was developed. Both audiences are treated equally, with ample possibilities and opportunities, without sacrificing the fun factor.

The remainder of this paper is structured as follows: Section 2 provides Theoretical Framework. Section 3 describes Related Works. Section 4 presents the Unseen Game and its prototype. Section 5 describes the prototype Evaluation. Finally, Section 6 addresses final considerations.

## 2. Theoretical Framework

The gaming industry has experienced exponential growth in recent years. However, despite the increasing interest in games, a large group of users is unable to play due to their disabilities, as accessibility features are often minimal in traditional games available on the market [Cheiran, 2013].

Programs of digital inclusion face numerous challenges in sharing knowledge and information to include these users in the information society. However, [Wrzesinska *et al.*, 2021] highlight that young individuals with visual impairments who engage in electronic games tend to exhibit better abstract reasoning skills, improved social interaction and self-confidence, and play more frequently compared to their non-disabled peers.

According to [Nesteriuk, 2018], an audiogame is a type of digital game that places sound as its central element. It encompasses mechanics, interfaces, output, and feedback, providing a more accessible digital entertainment experience for individuals with varying levels of vision. In this type of game, sound serves as a substitute for the visual element, and having effective auditory feedback is crucial for an optimal gaming experience. It enables gameplay based on exploration and investigation of the surroundings. Auditory feedback can take various forms, such as the sound of footsteps while exploring the environment, alerts indicating that further progress is not possible, information about whom the interaction is with and the success of that interaction, or confirmation of the player's actions, such as turning right after pressing a related button. These auditory feedback elements ensure maximum immersion, allowing the player to focus entirely on the game in a secure manner.

Another crucial feature that can be provided is audio description, which [Bourne, 2007] defines as verbal information inserted between dialogues, aiming to assist blind or visually impaired individuals in understanding what is happening on the screen. It is a technique of describing images, whether static or dynamic, providing relevant information about their audiovisual content. It translates images into words. [Bourne, 2007] clarifies that audio description is not just about describing what is seen but rather what is essential for understanding the work, therefore, it should be connected to it in a way that contributes to the organization of its meaning. It involves a detailed narration of visual aspects such as shapes, sizes, colors, positions, actions, textures, emotions, and more.

Inclusive games are more challenging to develop. According to [Chioccola, 2017], one of the main challenges in designing this type of game is creating games that also appeal to sighted players. An inclusive game should ideally be equally engaging, enjoyable, and challenging for both audiences. Striking a balance between accessibility for visually impaired players and maintaining the interest of sighted players poses a significant challenge in inclusive game design.

Audiogames utilize three-dimensional sounds as a substitute for visual information, serving as an accessible tool for stimulating orientation and mobility through entertainment [Balan *et al.*, 2015]. They help identify the direction, distance, and characteristics of the sound source, enhancing the user's sense of reality. By relying solely on the sense of hearing, for example, it is possible to determine the distance from the source of the sound, perceive when someone is approaching, and even discern the direction from which a particular noise or voice is coming. 3D audio guides and enhances the immersion of users, assisting the player in gameplay. These audio effects are achieved using commonly available stereo headphones.

Three-dimensional sound, or binaural audio, involves the complete manipulation of a person's spatial perception, creating the illusion of a virtual environment and sound source localization, utilizing the human ability to perceive sound in three dimensions. Binaural sound has the capacity to deceive the listeners, making them believe that they are actually present in the reproduced environments. The brain is led to believe that the listener is in a virtual world. Thus, binaural sound represents for audio what virtual reality promises for visuals: the 3D sensation of being in a complex and real environment [Gunzi, 2008].

The prototype of the Unseen game, developed by the Lab3D team, aims to explore the language of sound and the vast possibilities that the acoustic universe offers in terms of stimulating the imagination. Binaural audio, as a strategy, expands the possibilities of the game's narrative, encompassing aesthetic and technological experiences. The goal is to create a new dynamic that provides an immersive experience for the player.

## 3. Related Works

In this section, we discuss related works, their connections, and relevant comparisons with the proposed project. The games considered for comparison are The Vale: Shadow of the Crown [Vale, 2023] and Audiogame Breu [Breu, 2023].

The Vale is an action-adventure game with over five hours of gameplay, set in a medieval universe. The main character, a blind castle guardian, must explore a vast environment and face challenges. The game utilizes 3D audio resources and tactile feedback to immerse the player in the game's universe. The gameplay is similar to Unseen, featuring free movement and exploration of the environment through indicative sounds. However, The Vale goes further by allowing the player to also determine the distance of objects through sound, further enhancing immersion. Additionally, The Vale incorporates more gameplay mechanics, such as a sword combat system and an inventory system for navigation, buying, and selling. Scene descriptions are delivered by characters or when the main character asks their traveling companion to describe what they see.

Breu, a game produced by Brazilians and nationally recognized, tells the story of Marco, a young man who lost his vision at the age of 15 and began living with his grandfather in a small countryside town. He hears strange reports of missing residents, including his friends and his grandfather, which leads him to investigate the forest. Audiogame Breu and the Unseen project share some similarities, such as main menus with audio description and an investigative narrative. However, Breu adds a survival horror element, while Unseen has a more visual setting and a different gameplay mechanic. Breu is fully voiced, with each character having their own voice, while Unseen uses synthesized voice throughout the game. Additionally, Breu does not utilize 3D audio technology, which is essential for playing Unseen. Both games allow the player to explore and interact with objects in the environment to uncover clues and progress in the story, but the way this is done is quite different. In Breu, the player cannot move through the environment but instead selects what he/she wants to interact by using the left and right keys and then pressing the ENTER key. In Unseen, the player can move on a 7x7 grid and freely interact with objects in specific cells.

## 4. Unseen Game

The Unseen project aims to provide an immersive 3D experience through a digital game. It is designed as a serious game with an educational purpose. The prototype was developed using Unity Engine, along with Visual Studio 2019 software and the Windows 10 Pro operating system, on a desktop computer with the following specification: an Intel(R) Core(TM) i7-7700 CPU @ 3.60GHz processor, 16 GB of RAM, an HD Graphics 630 video card, and STEREO Headphones IG-7537.

The game takes place in the "Rare Works" Museum hall, which exhibits three artworks. The hall is structured in a grid pattern of 7m x 7m. As the player moves through the hall, he/she can interact with people, who can be either employees or visitors, objects, artworks, and games.

The player wins the game when he/she unravels the mystery and discovers which artwork is the fake one. The target audience includes both visually impaired and sighted individuals. In the game, the player is portrayed as an explorer-type character. He/she is challenged to find clues throughout the salon, attempting to decipher the game's puzzle. The player explores the entire scenario through interactions to uncover hidden items.
While exploring the salon, the player is also challenged to play two mini-games: Genius and Sound Memory Game, with the objective of obtaining more clues to unravel the mystery. In the Genius Game, the player must reproduce the sounds heard in the same ascending sequence presented. In the Sound Memory Game, the player must uncover pairs of identical sounds in a 2x3 table.

As an educational game (serious game), it has the following requirements: it raises awareness among people about what an accessible museum is, providing items commonly found in such museums (e.g., audio descriptions of artworks, braille text on interactive items etc.); it demonstrates empathy towards the visually impaired audience by offering a game guided only by audio; and it explores audio descriptions of artworks by providing details, trivia, and testimonials, fostering knowledge and engagement with the artworks, even for sighted players.

Other important requirements of the game include: despite being a game without visual resources, it should strive to prevent the player from feeling lost in the salon; the game provides immediate auditory feedback for each player action; through binaural audio, it immerses visually impaired players in the 3D world, offering an immersive experience through positional sound; and it ensures enjoyable entertainment for both sighted players and those with visual impairments.

The electronic game can be described using the MDA model proposed by [Hunicke, 2004]. This model divides a game into three components: mechanics, dynamics, and aesthetics. Mechanics refer to the rules that govern the game, dynamics are the systems formed by the mechanics, and aesthetics are the emotional responses that the player experiences during the game. Therefore, the use of the MDA model allows us to understand how the game works and how it emotionally impacts the player.

### 4.1 Mechanics

Within the MDA model, mechanics represent the fundamental elements that make up the game. These elements encompass all the rules, behaviors, and actions that a player can perform within the context of the game.

The rules and mechanics of the game are as follows:

- Using the vertical arrow keys or the "W" and "S" keys on the keyboard, the player can take a step forward or a step backward.
- Using the horizontal arrow keys or the "A" and "D" keys on the keyboard, the player can rotate 90 degrees to the right or left, directing his/her character within the grid.
- When approaching an object with interaction possibilities, a musical note indicating the position of the object will play. For example, a sound to the right will be emitted if the object is positioned to the right of the character.
- When hitting a wall, a distinctive sound will play, indicating that the player cannot move in that direction.
- Pressing the ENTER key allows the player to interact with objects or people, or for audio prompts.

### 4.2 Dynamics

In the MDA model, dynamics are the result of the player's actions through the mechanics.

Although the game does not have a visual interface, it is represented by a 7x7 grid. Clues, people, artworks, and mini-games (Sound Memory Game and Genius Game) are located within the cells of this grid. As the player moves through the salon, they hear a signal indicating the presence of an object for interaction, either in front, to the right, or to the left. The player positions himself/herself in front of the object, presses the ENTER key, and receives a clue, an audio description of an artwork, or the opportunity to interact with a mini-game.

The feedback that the player receives for smooth navigation includes:

- A musical note indicating the position of an object for interaction.
- A distinctive sound indicating collision with a wall.

- Footstep sounds when moving through the salon.
- Audio providing hints to solve the game's puzzle.
- Audio descriptions of the three exhibited artworks in the museum.
- Audio descriptions of menu options within the game.

Due to the importance of the audio played during the game, which needs to be heard by the participants at different volumes and sometimes only in one of the earphones, it was decided not to provide the same audio to the evaluators. This decision would make it challenging for them to track the player's progress and location during the game. Therefore, during the evaluation (which will be detailed in the next section), it was chosen to provide the evaluators with a visual representation of the environment to facilitate their understanding. Figure 1 illustrates the 3D environment in the Museum Room, showcasing all the objects available for interaction. It is worth noting that none of the test participants had visual access to this environment during the study.

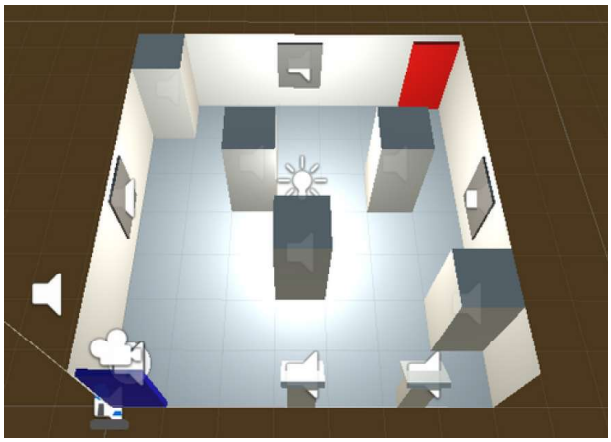

**Figure 1: 3D environment representing the Museum Room with all objects available for interaction.**

### 4.3 Aesthetics

In the MDA model, aesthetics refer to the emotional responses evoked in the player through his/her interaction with the game. In the Unseen game, the following aesthetics were identified: Challenge, Sensation, and Discovery.

"Challenge" is defined as the feeling of overcoming a task skillfully and efficiently. It encompasses the sense of accomplishment and satisfaction that arises from successfully navigating the gameplay challenges.

"Sensation" is associated with pleasurable sensory stimuli, including auditory feedback, that emerges from the player's actions. It aims to engage the player's senses and create an immersive and enjoyable experience.

Finally, "Discovery" is the sensation of exploring uncharted territory. It encompasses the excitement and curiosity that arise when uncovering new information, interacting with objects, and discovering hidden aspects of the game world.

These aesthetics work together to create a compelling and engaging experience for the player, providing a sense of accomplishment, sensory pleasure, and a desire to explore further.

## 5. Evaluation

After developing parts of the game prototype, it was necessary to conduct an evaluation of the game to identify interaction problems that could hinder its usability. The evaluation involved collecting qualitative and quantitative data through questionnaires, observing users interacting with the audiogame, and conducting a semi-structured interview. The research aimed to uncover elements of interaction that would leave the user satisfied, motivated, prone to errors, and to determine if the navigation methods in the environment were clear.

The test was conducted in person at Lab3D (Virtual Reality Laboratory) of COPPE, located at the Federal University of Rio de Janeiro (UFRJ), using headphones and a computer with the prototype installed. The participants chosen for the research included individuals with visual impairments and sighted individuals to carry out the tests under the same interaction conditions, only via audio (Figure 2). A total of six tests were conducted with users, the first one being considered a pilot test. The tests involved three sighted users and two blind users. These participants were required to have knowledge of computer usage and electronic games. To structure the tasks and activities of the test, the following three areas of the audiogame were considered: Sound Memory Game, Genius Game, and Museum Room.

**Figure 2: Participant navigating the Museum Room wearing headphones and blindfolded.**

One specific issue to highlight is that the test was conducted with users listening through headphones, and it was not possible to have two audio outputs. Therefore, the researchers could not simultaneously hear the audio in the Sound Memory Game and the Genius Game. The researchers were able to track the progress in these games through on-screen information about the hits and misses. However, in the Museum Room, the visual interface of the prototype development software was used to monitor and observe the participants' interaction with the game.

Students from the Bachelor's degree program in Computer Science at UFRJ were invited to participate in the test to facilitate their transportation to the testing location. The blind participants were escorted by the team both to and from the designated location, since the access to the laboratory is through a staircase leading to the basement

of the building. Upon arriving at the testing location, an introduction was provided, describing the project and the objectives of the evaluation. Then, a printed Informed Consent Form (ICF) was provided to the sighted participants, while it was read aloud to the blind participants. Subsequently, the participants completed the pre-test questionnaire online (Table 1), which included questions about their profile.

**Table 1. Comparative table of qualitative data of participants' profile.**

| | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| **Age** | 20 | 19 | 20 | 24 | 43 |
| **Schooling** | Higher education | Higher education | Higher education | Higher education | Higher education |
| **Gender** | M | M | F | M | M |
| **Visually Impaired Person** | No | No | No | Yes | Yes |
| **Gaming Habit** | Yes | Yes | Yes | Yes | No |
| **Gaming Platforms** | PC, Smartphone | PC, Smartphone | PC, Smartphone, Console | PC, Console | PC |
| **Frequency of playing games** | Sporadically | Sporadically | Sporadically | Two or more times a week | Never (discouragement) |
| **Player skill level** | Intermediary | Experient | Beginner | Experient | None |
| **Previously played audiogames** | No | No | No | Yes | Yes |

At this point, the sighted participants were asked to blindfold themselves to begin performing the tasks. The instructions for each module's activities were given to the participants, and all interactions were recorded on video and also noted in the printed monitoring script. Only after completing all the tasks did the researchers ask the post-test interview questions. Some structured interview questions were related to the following categories: Game Instructions (Are the instructions clear? Did anything seem difficult to interpret/understand?); Types of Sounds (Are the sound effects intuitive?); Position of The 3D Audio (Is the "position" of the sound easy to distinguish? Can you hear clearly/easily where the sound is coming from?); Location (Was it easy to find the works to listen to the audio description?); Content (What did you think of the descriptions of the works?); Usability (Did you have any difficulties when testing the game? What do you think should be improved in this game to make it more accessible and easier to use?).

### 5.1 Evaluation Observations

In the Museum Room, after listening to the game instructions and freely exploring the environment, participants were asked to find artwork and listen to an audio description. They were also instructed to search for game hints. The purpose of this task was to assess whether users could navigate and orient themselves within a 3D sound environment. Once participants completed the tasks, the game was concluded, and the researchers proceeded to the next test module: the Sound Memory Game. The Museum Room proved to be the most challenging task and took the longest time to complete.

Participants felt lost, unsure of their location, and had difficulty orienting themselves. Suggestions were made to improve the interaction sound with objects, the sound when encountering walls, and the addition of other noises, such as background conversations, to enhance the immersive experience. Some of the participants' comments during the interview included: "Actually locating myself in the Museum Room and knowing which direction I was turning, at the beginning, was the most difficult part" (P1); "At first, I was lost, walking diagonally" (P2).

In the Sound Memory Game, in addition to listening to the instructions, participants performed a sound test that demonstrated the game's interaction sounds. After that, participants were required to explore the 6 cards and find card number 6. Once a participant indicated he/she had found it, the game was reset, and the participant played the full game. The purpose of testing this module was to assess whether users could understand the game instructions and perceive different types of sounds while playing. In the Sound Memory Game, participants found the sound test feature interesting, and the instructions for the game were clear. The sound of the cards flipping was intuitive, and this game was considered the easiest. Regarding this game, participant P4 emphasized during the interview: "The instructions are okay, and the audio test is so clear that it doesn't even require documentation. The sound effects were easy to remember and understand to make a match."

In the Genius Game, it was also possible to perform a sound test of the game after listening to the instructions. The game was then reset for the participant to play and reach level 5, which represents a higher level of difficulty. If desired, they could try to complete the game by reaching level 8. The objective of testing this module was to identify if users could perceive the different locations of the 3D sound. In the Genius Game, participants found it easy to identify the location of the simulated sound in a 3D environment. A positive aspect was the use of different types of sounds to facilitate recognition. Participant P1 stated, "I could definitely tell the position of the sound." The game mechanics (increasing sequentially) should be emphasized to aid in understanding and completing the task, as pointed out by P4: "I found it easy, but it wasn't clear that it's a progressive sequence. I thought it would automatically repeat immediately."

### 5.2 Insights from the evaluation and recommendations

Use of numeric keys in the menu: two participants mentioned that it was difficult to determine the position of the numbers to navigate the menu identified with numbers. Web navigation with screen readers follows an ordered sequence. Therefore, it was recommended to use the arrow keys on the keyboard for all menu navigation.

Questions about the end of audio tracks: one participant was unsure if an audio track had already ended. Since sound is the only interaction resource in the audiogame, there are no other senses to be explored. Therefore, it is necessary to reinforce auditory feedback and/or use some sound resource to indicate the start or end of an audio track.

Sound testing enhances understanding: participants found it easier to play games that had an audio test at the beginning. They requested an audio test for the Museum Room game. As next steps to be taken, an audio test should be implemented for the Museum Room game to help players understand the different forms of interaction and feed.

Improving location awareness in the Museum Room: the greatest challenge was indeed spatial orientation within the Museum Room, as it is a more complex game that requires more resources to explore. Implementing additional features to facilitate spatial location within the Museum Room is necessary. This was one of the main issues identified during the evaluation, and some suggestions from the participants included: clearer feedback on footsteps, direction, walls, and objects, as well as the use of a radar system.

### 5.3 Qualitative and quantitative analysis

As a result of the game evaluation (Table 2), the average time to complete tasks in the Museum Room was 5.33 minutes for sighted participants (P1, P2, and P3) and 7 minutes for blind participants (P4 and P5). The average time to complete tasks in the Genius Game was 1 minute for sighted participants and 1.5 minutes for blind participants. Finally, the average time to complete tasks in the Sound Memory Game was 2 minutes for both sighted and blind participants. Therefore, the individual average time for each task remained very close both to sighted and blind participants. Despite blind participant P5 being the only participant who did not have a gaming habit (Table 1), he did not show any difficulty and was able to complete all test tasks. Participants consistently stayed within the average task execution time even though they declared different levels of gaming skill (Table 1).

**Table 2. Comparative table of quantitative test data showing the average time, in minutes, taken by each participant to complete the task.**

| Task time (minutes) | P1 | P2 | P3 | P4 | P5 |
|---|---|---|---|---|---|
| **Sound Memory Game** | 3 | 1 | 2 | 3 | 1 |
| **Genius Game** | 1 | 1 | 1 | 1 | 2 |
| **Museum Room** | 8 | 5 | 3 | 10 | 4 |

All participants encountered greater difficulty in the Museum Room, as expected, due to its higher complexity. The 3 sighted participants had never tried an audio game (Table 1) and managed to complete all the tasks without help and without giving up, just like the 2 blind participants who had already tried audio games previously. One blind participant expressed himself as follows: "It's simple, but it's an entertaining game, an incredible pastime. I never thought I would see a structure like this, especially because it was created by sighted researchers who are concerned with developing for this audience and making it accessible. It's a commendable initiative." According to [Chioccola, 2017], the prototype of the Unseen game has proven to be an inclusive game, as it is equally appealing, fun, and challenging for both audiences.

As a conclusion of the evaluation, it was observed that both sighted and blind participants felt immersed in the constructed environment. With the use of binaural audio technology, it was possible to involve a blind participant in the 3D world, which is primarily visual and very limited for this type of audience. One blind participant responded in the interview: "I felt immersed in the 3D world, it's cool, and the navigation is interesting."

## 6. Conclusions

With the development of the Unseen game prototype, it was possible to realize that the use of binaural audio for games that include visually impaired individuals still has a long way to go. Even with examples of some related works, the gameplay needs to be improved. However, the prototype serves as an example that aims to immerse this target audience in a 3D world, which until recently was only available to sighted individuals. Based on the evaluation conducted, it is clear the need for a similar path to follow for this type of game to best meet the needs of this new market niche.

One of the main limitations of the prototype identified is the lack of a screen reader, which would allow visually impaired individuals to control the speed, voice type, and other settings with ease. The initial idea of the game was to have sounds positioned in different locations to create an immersive experience for the player, but this kind of feature needs to be carefully calibrated. In this first version, however, this feature was not implemented. The audio would have filled the environment as a way to illustrate what was happening in that space.

Despite advancements in 3D technology, visually impaired individuals still face significant barriers when it comes to accessing 3D world games. Therefore, the main contribution of this research is that it has proven the need for an inclusive game, allowing individuals to experience, understand, and suggest new initiatives and opportunities to be explored. It has the potential to pave the way for further advancements in inclusive gaming and promote accessibility in the gaming industry.

As future work, this project aims to be expanded by incorporating screen readers that allow personalized configuration of the audio to be played. It will also seek to enhance positional ambient sounds to enrich the player's understanding of what is happening in the explored salon. Additionally, the project aims to add different levels of gameplay and introduce new mini-games that challenge the player. These developments will contribute to a more immersive and engaging experience for both visually impaired and sighted players.

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