LiU-ITN-TEK-A--22/057--SE

Escape the Decision Arena - Designing and evaluating an immersive collaborative gaming experience in a cylindrical environment

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The thesis work carried out in Medieteknik
at Tekniska högskolan at
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Abstract

The Decision Arena in *Linköping University* contains a 360° cylindrical display with a complementary 360° sound system consisting of eight evenly spaced speakers along the bottom edge of the screen. This paper explores if an immersive game can be developed for such a non-typical gaming environment. The result was a two-player cooperative puzzle-solving game inspired by Escape Rooms where the final product was evaluated through playtesting, questionnaires and interviews by participants. The game was developed using *Unreal Engine* for the graphics and game logic, *SuperCollider* for sound implementation, and a custom website was used to control the game, which uses *WebSockets* to communicate with Unreal Engine. The evaluation results show that most participants found the game immersive and engaging, which points to that it is possible to develop immersive games for the Decision Arena. According to feedback, the most challenging, and sometimes immersion-breaking, aspect of the game was localizing the sound. The evaluation results also suggests that certain sounds are easier to localize in the Decision Arena than others, which led to the conclusion that further research in sound localization is beneficial if more sound-based games were to be developed for this environment.

Acknowledgments

We would like to first and foremost thank Elias Elmquist for being an outstanding supervisor. The support and advice we have gotten throughout these months have been more than we deserved, we truly appreciate everything that you have done for us. We could not have asked for a better aid than you – thank you for making our lives easier. Also, a huge thanks to Andreas Palm a.k.a. Anden for giving us a helping hand in the WebSocket department. Last but not least, a heartful thank you to our examiner Niklas Rönnberg. We truly appreciate that you supported our ideas from the very beginning and basically let us follow our hearts for this thesis, helped us strengthen the concepts and gave us helpful resources to fully understand all the different concepts we wanted to incorporate into this project. Thank you for giving us this unique opportunity that we will forever remember and look back to with pride and joy.

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1 Introduction

The Decision Arena in *Linköping University* at campus Norrköping is a unique facility with nine projectors that can project a computer screen onto a 360° cylindrical display, along with eight evenly spaced speakers to complement the projected image. Having a cylindrical display with complementing sound system is an unusual environment and the possible uses for them are many, though most of them are unexplored.

1.1 Background & Motivation

The Decision Arena is mainly used for meetings and presentations. It was made for presenting, visualizing and discussing different types of information in a lucid way, and to enable these kinds of meetings in a non-hierarchical manner through its circular shape. The arena is six meters in diameter with a table that is about two meters in diameter. The table has eight input stations where users can connect computers whom are then displayed on the cylindrical display – see figure 1.1.

Because of the immersive characteristics of the Decision Arena, there is potential to design and develop an immersive game which utilizes the cylindrical display and surround sound system. This will be the main focus of this master thesis. Specifically, the goal is to design a multiplayer puzzle-solving game where two players have to collaborate to solve puzzles together by finding clues and observing the game's internal environment.

Various kinds of games could be implemented in the Decision Arena, however since the Decision Arena display physically shuts people in, a possible type of game genre to be implemented there could be an *Escape Room* [24]. An Escape Room is a kind of game played in a physical facility by multiple people where the objective is to work together in order to escape one or several rooms. The players search around the room to find keys, clues or patterns which are then used to solve puzzles or riddles, eventually leading to the players unlocking the exit and "escaping". Another game that sparked inspiration is *Keep Talking and Nobody Explodes*[1], which is also a collaborative multiplayer video game, though here the objective is to disarm a bomb by working together. Completing this game with only one player is

[1]Keep talking and nobody explodes: https://keeptalkinggame.com/ (Fetched: 2022-06-28)

impossible, which is a concept to be incorporated in the game that will be developed for the Decision Arena in this thesis.

Figure 1.1: The Decision Arena with the table and chairs in the middle of the room and the cylindrical display in the back. Three projectors can be seen on the top of the image.

1.2 Aim

The purpose of this master thesis is to test the capabilities of the Decision Arena's cylindrical display and sound system by implementing an engaging and immersive multiplayer game while utilizing the spacious environment of the room. Another focus point is to create a game that engages both players and encourages collaboration, rather than having them compete against each other. The level of immersion and collaboration of the game will be measured through user tests and evaluations after the participants have played through the game in the Decision Arena.

1.3 Research Questions

This thesis aims to answer the following research questions:

- What are the benefits of utilizing a cylindrical display when creating a collaborative gaming experience in the Decision arena?
- What game logic and mechanics will encourage a collaborative gaming experience in the Decision Arena?
- What are the design considerations in terms of sound, visuals and interaction that contributes to an immersive experience when developing a game in the Decision Arena?

1.4 Delimitations

The game is restricted to two players, and the game will only be fully playable in the Decision Arena in Norrköping since the game is tailored to the Decision Arena's cylindrical display and sound system of the environment. Therefore no other kind of screens like flat-screens, VR etc. were considered in this project. Furthermore, since the project includes several implementation aspects, the depth of the development is limited for each aspect. An existing game engine is used for developing the game instead of creating a custom one, free 3D models from the internet are used, and sound files also fetched from the internet are used instead of custom created sound effects. It must be taken into consideration that the table cannot be removed from the facility nor moved within it.

2 Theory

In order to understand how an immersive game can be designed in the Decision Arena, the concept of immersion needs to be introduced, followed by theoretical aspects surrounding sound design, user interface and game design. From hereon, the words *user* and *player* will be used interchangeably to describe the person playing the game.

2.1 Immersion

Immersion is something almost everyone knows what it means but the definition of immersion is still unclear. One important aspect to mention is that one does not play a game for the purpose of getting immersed, per se. Immersion is something that can occur while playing a game, like a positive bi-effect, and is key for a good gaming experience.

2.1.1 Types of Immersion

Immersion is a broad topic and something that is difficult to narrow down into a general definition. In fact, immersion can be divided into categories which enables one to refer to various engagement modes since immersion can be experienced in different forms. M. Haggis-Burridge [12] argues that immersion can be categorized specifically for video games and suggests four definitions:

System immersion – describes how deeply engaged the players are with the mechanics, challenges and rules of a game. Similar to a state of *flow* that will be mentioned later in section 2.1.3.

Spatial immersion – measures how present in, or transported to, the player is to the virtual world. This connects to *presence* that will also be mentioned in section 2.1.3. Haggis-Burridge also adds that it links to the concept of *embodiment* [17].

Empathic/social immersion – the connection that the player develops towards in-game characters (AI:s) or other human players, and the social context of the game.

Narrative/sequential immersion – describes the player's drive to get through all events

and the narration of the story, but also progressing by exploring new spaces and evolving gameplay mechanics.

C. Zhang et al. [27] compared spatial immersion versus emotional immersion to see which one is more immersive, and also brings up an array of various types of immersion. They conclude that the perception of immersion is different for each individual, and that different immersion types are more immersive than others in certain aspects. Emotional immersion is explained by them as "the type of immersion when the user feels emotionally aroused and absorbed by the narrative content of the story", and they refer spatial immersion to "the type of immersion triggered and maintained by the spatial qualities of the virtual environment".

2.1.2 Levels of Immersion

There are three levels of immersion that were identified in a study by E. Brown and P. Cairns [6], where **engagement** is the first level, **engrossment** is the second level, and the final level is **total immersion**. To reach engagement, they suggests that the player needs to invest time, effort and attention in order to learn how to play the game, as well as familiarizing with the controls. Furthermore, reaching engrossment implies that the player's emotions are directly affected by the game, and controlling the game comes natural to them as if the controls were invisible. At this point, it is stated that they are less aware of their surroundings, even less self-aware. These two levels are the more common experiences for players, whereas the final level that is total immersion implies highest level of attention which is a rare case.

However, immersion is not a phenomenon that only occurs for video games. Immersion can be experienced in different forms for each individual, it is highly personal how easy or difficult one becomes engaged or immersed. A finding that was made in a study by N. Haywood and P. Cairns [13] suggests that immersion has the following features:

- Lack of awareness in time.
- Lack of awareness of the real world.
- Involvement and a sense of being in the task environment.

2.1.3 Measuring Immersion

Since immersion is personal and differently perceived, a concrete way to measure and define it needs to be establish in order to do an accurate study on immersion. Jennett et al. [14] explores the development of a questionnaire regarding measurement of video game engagement which introduces three main ideas when constructing questions for immersion measurement: *flow*, *cognitive absorption*, and *presence*.

Flow is a term used to describe a positive experience, which was defined by M. Csikszentmihalyi – "the state in which individuals are so involved with an activity that nothing else seem to matter" [7]. A study made by J. Brockmyer et al. where a Game Engagement Questionnaire (GEQ) was developed also mentions flow when measuring immersion [5]. J. Brockmyer et al. explain that flow is achieved when balancing skill and challenge while performing a rewarding activity, furthermore that having a goal and immediate performance feedback increases the likelihood of flow, as well as enhancing learning. Furthermore, they suggest that "flow states also include a feeling of being in control, being one with the activity, and experiencing time distortions" [5]. The characteristics of flow overlaps with immersion in some sense – however it is important to note that their definitions are not interchangeable with one another, and that it is more common to become immersed than entering the flow

state. C. Jennett et al. also backs this up, stating that "flow is a particular sort of experience, specifically an optimal and therefore extreme experience. Immersion is not always so extreme".

Cognitive absorption is described by R. Agarwal and E. Karahana [2] as a state of deep involvement with software, whose main goal is to "enrich understanding of user reactions to information technology". The difference between immersion and cognitive absorption is that the former is the experience of performing an activity, and the latter is "an attitude towards information technology in general". An important note that is made by C. Jennett et al. is that curiosity is not a motivation for immersion, whereas for cognitive absorption it is. The factors that are measured for cognitive absorption are: temporal dissociation, attention focus, heightened enjoyment, control and curiosity. In this case, one can be absorbed in playing games, but not be very immersed.

Presence is a term commonly found in papers regarding immersion and user engagement in activities, which J. Brockmyer et al. defines by:

- being in a normal state of consciousness,
- having the experience of being inside a virtual environment.

The last point is strengthened by J. Rigby et al. who states "spatial presence and the feeling of being physically located somewhere other than the real world" [21]. A study by B. Witmer and M.J. Singer [25] found that "the naturalness of the interactions with the virtual environments and how much they mimic the real-world experiences affected how much presence they reported". Another study by P. Zahorik and R.L. Jenison [26] claims that "when the environment responds to the user's actions in a way which is perceived as lawful, presence is more likely to occur". A conclusion that Jennett et al. draws is that presence is a state of mind whereas immersion is an experience in time. Games can be immersive but not make the players feel present in the environment, and in the other way around a player can feel present but not immersed.

2.1.4 Evaluating Immersion

Since immersion can be experienced in different ways and levels, one approach to evaluate immersion would be to give the evaluation participants a questionnaire with statements where they can rate their experience. This is an approach to get quantitative research data and an overview of the immersion levels. Another approach would be to do a qualitative research approach by discussing the tester's experience through an interview. This way the participants can explain their thoughts and their replies can be interpreted to an immersion category that seems fit. Other than simply asking "Did you feel immersed?", questions such as "How much time do you think you spent doing this activity?" or "Did you forget about the time while doing this activity?" will be more effective in evaluating their time distortion experience – which links to engrossment and temporal dissociation that is mentioned earlier in sections 2.1.2 and 2.1.3. Furthermore, their involvement in the activity can be measured with questions like "Did you forget your everyday concerns?" and "Did you think about what to do after this activity is over?". Questions regarding presence could be "Did you feel transported from reality during the activity?", and for system immersion "How was it to control this activity? Did it come natural? Did you put effort into it?", et. cetera. In conclusion, thinking about including questions that relate to the different aspects that connects to immersive experiences will result in a more well-grounded and accurate study.

2.2 Sound

Sound is crucial for an immersive gaming experience, and audio from the game environment has to match sounds from the real world for immersion to occur [15]. For this thesis it especially means that the direction of the sound will be important. Since there are eight speakers in the Decision Arena it is important that the sound comes from the speaker which the players expect the sound to come from to maintain the immersion.

2.2.1 Sound Localization

Sound localization is the human ability to determine where sound comes from. Since the Decision Arena has eight speakers that surrounds the players, sound localization will be something important to consider. To make an immersive experience the sound needs to be played from the correct speaker in the Decision Arena to match with the graphics on the cylindrical display. Also, if the speakers are used to give the players information for solving puzzles, it must be ensured that the players find it easy enough to localize which speaker the sounds come from, or else the players risk finding the game frustrating.

Interaural Time Difference (ITD) – is the ability to localize sounds through small time differences called ITD. If a sound comes directly from the right, the sound will first hit the right ear and then the left ear after a short delay. ITD is useful to localize low-frequency sounds less than 1500 Hz [22]. This is because if a sound has less than 1500 Hz, the sounds wavelength is greater than the length of the human head, which means that the sound waves will be diffracted around the head. This leads to a phase difference between the sound waves entering the ears which is detectable by the human brain.

Interaural Level Difference (ILD) – is the ability to localize sounds through small intensity differences called ILD. If a sound comes directly from the right again, the intensity will be greater in the right ear than the left ear since the head absorbs some of the energy of the audio and therefore muffles the sound slightly. If the frequency is greater than 1500 Hz, the wavelength is smaller than the human head which means that the waves will not diffract as well and create a so-called *sound shadow* that lowers the intensity of the sound. The head also absorbs and reflects sound which contributes to the sound shadow. This means that the intensity difference between the ears is greater for higher frequencies and thus ILD is useful for localizing high frequency sounds. According to M. Risoud et. al [22], localization accuracy for ITD is good for frequencies lower than 1000 HZ, mediocre between 1000–3000 Hz and impossible for frequencies over 3000 Hz. For ILD localization accuracy is impossible for frequencies lower than 1000 Hz, mediocre between 1000–3000 Hz and good for frequencies over 3000 Hz.

2.3 User Interface

User interface, or UI, is a term that falls under the concept of **HCI** – human-computer interaction – which defines the way of interacting and communicating with electronic or digital devices and computers [23]. User interfaces are display screens, computer mouse, keyboards and essentially any physical controls. Furthermore, there are different types of UIs. Perhaps the most well-known are the graphical user interface (GUI), touch UI, and menu-driven UI. Modern technology revolves around digital applications which has resulted in a burst of popularity for UI developers and studies in this particular field.

When designing or creating a user interface, focus is usually on making it *intuitive* [18] – meaning that once an interface is presented to the user it should only take a short moment or a few tests before the user understands what effects their actions has. A well-designed

UI should behave accordingly to the user's expectations, and there are various principles and guidelines when it comes to designing an intuitive interface. Norman's book on design principles [19] can be used as a general guideline even when creating digital UIs where terms as *feedback*, *visibility* and *affordance* are introduced, and taking them into consideration is a factor that results in a successfully intuitive interface.

2.4 Game Engine

A *game engine* is a software made primarily for developing video games, but can be used for other purposes such as creating cinematics. Game engines are provided with rendering engines for graphics, a physics engine, animation support, and AI amongst many more functionalities that are needed for various 2D and 3D graphic projects. Some of the most popular game engines are *Unreal Engine*[1] from Epic Games, *Unity*[2] by Unity Technologies, and *Game Maker*[3] by YoYo Games. Unreal Engine is primarily a 3D computer graphics game engine – but can be used for 2D graphics as well – which was originally designed for first-person shooter games in 1998. Over the years, the engine has expanded at rapid pace and is now used for any type of game imaginable, several AAA game titles[4], and is even used in the film industry. The engine is built on C++ and is known for its renders and visuals. Developers can either build their games in C++ or use the script language *Blueprints* that allows rapid development of logic and functionality even with minimum programming experience – one of the reasons behind its popularity. Unity on the other hand uses C# primarily for developing games, but have since 2020 their own visual scripting language *Bolt*.

2.5 SuperCollider

SuperCollider is an IDE – integrated development environment – for audio synthesis and composition algorithms. In this platform, synths can be defined that plays whatever sound has been specified in the synth. The sound can then be programmed to play from any speaker at any time. SuperCollider creates a local server where all the synths and sounds are hosted and then the client side of SuperCollider can call the synths which plays the correct sound.

2.6 Open Sound Control

Open Sound Control (OSC) is a communication protocol that can be used between computers or synthesizers for sending audio-data in real-time through a network. Both SuperCollider and Unreal Engine are integrated with OSC, therefore allowing communication between the two programs. By using Unreal Engine's own OSC plugin [5] messages can be sent to SuperCollider whenever sound or sound effects are supposed to play. The message tells SuperCollider which synth to play and contain variables like integers or floats, which enables changing and controlling the sound in SuperCollider directly from Unreal Engine.

2.7 WebSockets

WebSockets[6] is a bi-directional communication protocol used for communicating between a server and a client [11]. Unlike HTTP protocols, which is unidirectional where the connec-

[1]Unreal Engine website: https://www.unrealengine.com/en-US/ (Fetched: 2022-06-28)
[2]Unity website: https://unity.com/ (Fetched: 2022-06-28)
[3]Game Maker website: https://gamemaker.io/en/gamemaker (Fetched: 2022-06-28)
[4]20 Great Games That Use The Unreal 4 Engine: https://www.thegamer.com/great-games-use-unreal-4-game-engine/ (Fetched: 2022-06-28)
[5]Unreal Engine OSC: https://docs.unrealengine.com/ (Fetched: 2022-06-29)
[6]The WebSocket API: https://developer.mozilla.org/en-US/docs/Web/API/WebSockets$_{API}$ (Fetched: 2022-08-05)

tion terminates after the client sends a request and the server sends a response, WebSockets carries a stateful protocol meaning that the connection between server and client is kept alive until closed by either party. Similar to HTTP, a WebSocket connection starts with the client sending a request to the server. Instead of the server only sending a response and ending the connection, it responds with a handshake. If both parties decide to keep the connection alive, then that creates a WebSocket connection – figure 2.1 illustrates how the connection is made. Messages can then be sent between the parties back and forth. WebSockets is useful for various purposes when it comes to real-time applications, for example it is used for gaming where data continuously needs to be received by the server, or in chat applications. It is most useful when a real-time update or continuous streams of data are being transmitted over a network. However, for fetching old data for a one-time only processing, HTTP protocol is a more appropriate choice.

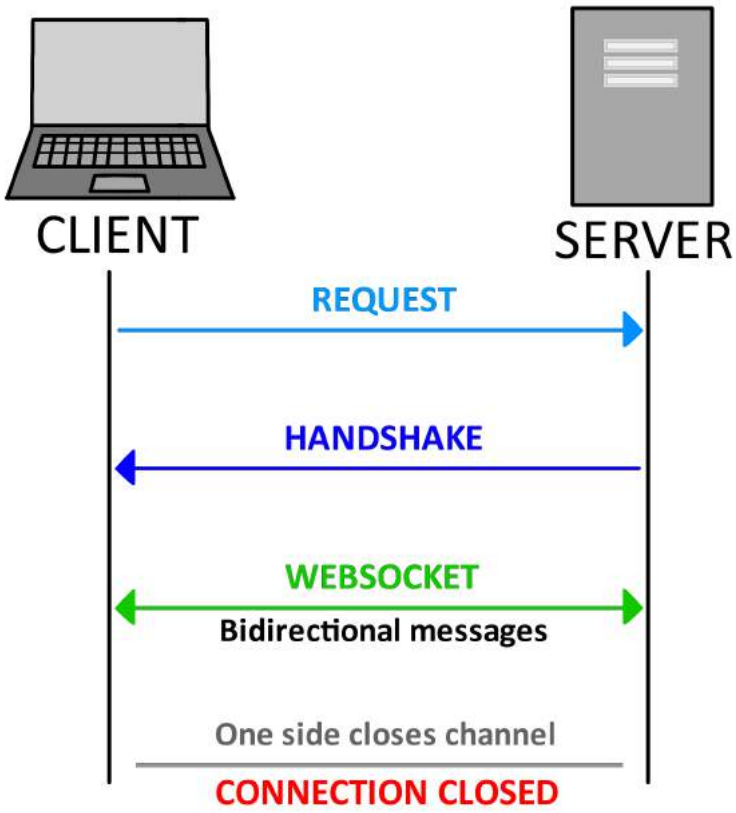


Figure 2.1: Illustration over how WebSocket connection works.

2.8 Collaboration

The essence of cooperative multiplayer games is to make the players cooperate to solve interdependent tasks, and having a group of players solving tasks together increases the sense of cooperation [8]. In order to achieve a successful collaboration, tasks must be difficult enough to spark discussion between players where they can observe, explain and justify their theories [3, 20]. Examples of cooperate multiplayer games are *Keep talking and nobody explodes* by Steel Crate Games that was mentioned in section 1.1, and *It Takes Two*[1] by Hazelight

[1]It Takes Two: https://www.hazelight.se/games/it-takes-two/ (Fetched: 2022-06-28)

Studios.

2.9 Related work

There are several different types of immersive environments, the Decision Arena is just one of many. *CAVE2* is one example that creates a panoramic view with a cylindrical display consisting of near-seamless flat-panels [10]. This environment enables users to simultaneously view 2D and 3D information, which is unique for this particular environment. CAVE stands for *Cave Automated Virtual environment* and is used for research, education and entertainment. It uses tracking to update the images on the screen according to one's location in the environment, and has immersive surround audio with a multitude of speakers. Examples of applications[1] are moving around a model of Mars, and exploring the insides of a human body such as organs, oxygen flow in lungs, and the nervous system in the human brain.

Another kind of immersive environment is a *dome theatre*[2]. There are several variations of this theatre, but what they all have in common is a dome-shaped, spherical display – hence the name, immersive surround sound and 360 degree horizontal view. The vertical view is what differs between dome theatres, ranging from 90 to 360 degrees. These environments are used for both educational purposes and entertainment, for example: planetariums[1] and 360 videos. *OpenSpace* is another space-related, live application that combined with the dome provides an interactive experience in order to visualize and discover more about the solar system and surrounding universes, and educate its audience [4, 16]. The OpenSpace application is similar to a game without the game mechanics, one can travel about the solar system and thus ask for audience input about where to go.

[1]Scope story on CAVE2: https://www.monash.edu/researchinfrastructure/mivp/impact/archive/stories/scope-story-on-cave2 (Fetched: 2022-07-07)

[2]What Is Dome Theatre?: https://forum-theatre.com/what-is-dome-theatre/ (Fetched: 2022-07-05)

3 Method

Game design including environment graphics, sound effects, puzzle design, UI design and system architecture is described in this chapter, followed by the different techniques and programs that were used for implementing the game, and evaluation procedure.

3.1 Game Design

The game created for this thesis followed the concept of a collaborative multiplayer puzzle/Escape Room game, where the goal of the game is to escape the Decision Arena which the players are "trapped" in. The idea was to let the players solve puzzles together where the cylindrical display projects the environment of the game, which is where the players will look for clues. In order to control the game, the players have access to a laptop with a website interface opened up where they have the options to enter the different rooms and input the solution for the puzzles. The game starts in a "control room" where the players have the choice to go into three different puzzle rooms using the website interface. Since the players are "trapped" in the Decision Arena and the goal of the game is to "escape", the name of the game thus became *Escape the Decision Arena*.

3.1.1 Game Environment

In order to enhance immersion, it was decided to let the game take place in an abandoned factory setting with visual details such as flickering lights, dust particles, electrical sparks, and water drops along with appropriate sound effects and eerie, ambient music to set the uneasy mood. Another factor that played into the choice of environment is that the Decision Arena has a natural echo in it, which is especially prominent when one is standing up. By letting the game take place in an abandoned factory environment, the echo can be incorporated in a natural way, since players could expect to hear echo in that kind of environment and could feel less distracting that way.

The final outlook of the game environment can be viewed in figures 3.2–3.7; keep in mind that the images had to be scaled down significantly to fit in the report since the original images have around 11000x1200 pixels each. *Google Drive* was chosen as the sharing method to view the full images, click **here** to study those with the possibility to zoom into the im-

ages. Furthermore, a short movie on YouTube is available **here** which presents the game environment complete with moving particle systems, flickering lights, sound effects and the triggered puzzle sounds.

3.1.2 The Puzzles

As mentioned previously, the game consists of three puzzles; all with varying difficulty and mechanics. They are, creatively, named Puzzle 1, 2 and 3. The numbers hint at which order the puzzles should be solved as they were designed to increase in difficulty – 1 being the easiest and 3 being the hardest. However, the puzzles can be solved in any order meaning that the players themselves can choose to solve the game in whichever order they wish, there is nothing forcing them to solve in chronological order if they do not want to. They are not stuck in a room once they go in, and are free to go into a different room however they like. A map over the game environment can be seen in figure 3.1, and figure 3.2 shows how the control room looks like on the cylindrical display. To give a better representation of how the control room is perceived in the arena, a panoramic view is available through **this link**.

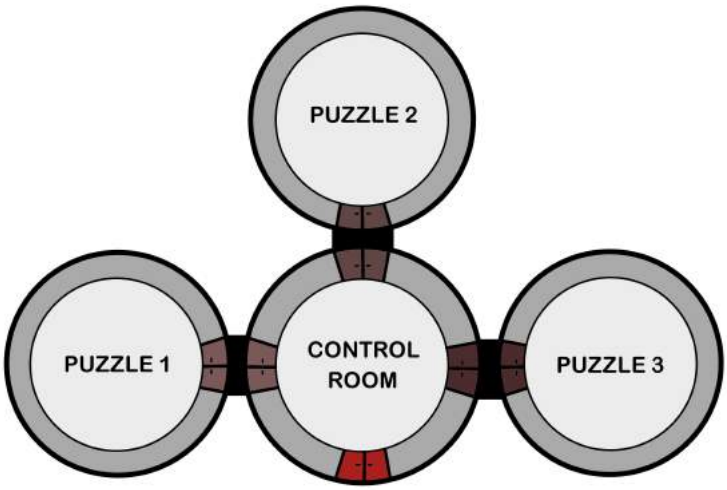


Figure 3.1: Map of the four game environment rooms.

All puzzles have a button which "triggers" the puzzle on the website. When the players press the trigger button, a code is revealed and the next step for the players is to input the solution into the website interface. Every code sequence generated is completely random. To see if the solution is correct they need to press a "check" button, where there are two outcomes: either the solution is false which causes the room to flash red and an incorrect buzzer sound is played, or the solution is correct which results in a green flash accompanied by a correct ding sound. When a puzzle room is cleared the lamp above the corresponding door to that room permanently lights up in green, both inside the room and in the control room. When all puzzles are cleared the light above the double exit door also turns green and an applause sound is played.

Figure 3.2: The Control Room. This is the first room the players see when the game starts.

3.1.3 Puzzle 1 – Flickering Light Puzzle

Figure 3.3: Puzzle 1 room environment.

In the first puzzle the players are in a dimly lit room as seen in figure 3.3. When the puzzle is triggered two random numbers appear for 0.2 seconds on opposite sides of the cylindrical display, see figure 3.4 for an example. The panoramic view of the room can be seen **here**. The numbers are positioned in a way that makes it impossible for one person to see both sequences at once. This means that the players have to split up and look at one sequence each and then enter the numbers one after the other into the website. The order of the input numbers does not matter, it is programmed in a way that does not have a bias towards placement in the arena. For example, the two sequences in figure 3.4 are 272 and 667, meaning that the correct input is both 272667 and 667272.

Figure 3.4: Puzzle 1 room environment where the puzzle is triggered, revealing the two number sequences on each side of the room.

Puzzle 1 is purely focused on the visuals and was designed to be simple in order for players to understand the concept of the game – both mechanically, and by encouraging cooperation since it is physically impossible to see the two number sequences in 0.2 seconds.

3.1.4 Puzzle 2 – Sound Sequence Puzzle

Figure 3.5: Puzzle 2 room environment.

In Puzzle 2 the players are in a room with eight speakers on the wall, where each speaker is assigned a number 1–8, see figure 3.5 or view the panoramic version through **here**. When the puzzle is triggered, a randomly selected speaker first plays a high-pitch sound, followed by another random speaker playing a low-pitch sound. This happens three times one after another, for a total of six sounds. The players have to localize the sounds and determine from which speaker the sounds come from, and at the same time keep track of the sequence for the high-pitch sounds and the low-pitch ones. The number corresponding to the speaker gives a number to the code which solves the puzzle. The high-pitch sounds give one code sequence to the puzzle and the low-pitch sounds give the second code sequence required to solve the puzzle.

This puzzle uses only audio to convey the code. It is meant to be more difficult than Puzzle 1 and introduce sound localization. The high-pitch sound has frequencies between 700–5000 Hz and the low-pitch sound has frequencies between 220–2850 Hz. This puzzle is

possible to solve alone since there is a short pause between the sounds, however sounds are difficult to localize, therefore the puzzle is still deemed challenging enough for two people – especially on a time limit.

3.1.5 Puzzle 3 – Clock Puzzle

Figure 3.6: Puzzle 3 room environment.

In Puzzle 3 the players find themselves in a room with the numbers 1–12 on the walls, thus resembling a clock. As seen in figure 3.6, the space between the numbers is not quite even. This is due to the physical speaker positions in the arena, since the thought behind the puzzle is to use sound position and visual cues to construct two separate times in hours and minutes. Since there are 12 numbers on a clock but only 8 speakers, the numbers 2, 4, 8 and 10 were chosen to be left out from the sound aspect of the puzzle – this is also strengthened by these numbers not having a speaker object below them.

As mentioned, the puzzle builds upon visuals and audio; a mix of the previous puzzles. When the puzzle is triggered, two numbers are lit up one after another, along with two bell-sounds – one high-pitched and one low pitched – playing also one after another. Figure 3.7 shows an example of the number 8 lit up, and the panoramic view can be studied **here**. The audio cues are played one time and the visual cues are shown another time, where the first sound and lit up number represents the hour-hand, and the second sound and lit up number represents the minute-hand.

Figure 3.7: Puzzle 3 triggered with number 8 lit up.

The inspiration behind this clock puzzle came from the room's circular shape. The point here is that the players divide the cues between them, one focusing on the visual cues and the other focusing on the audio cues. If the numbers on the wall is not enough of a clue for the players to conclude that they are standing in a clock, then the audio cue being a bell would help them in the right direction, along with a clock-ticking sound effect added to the background ambience. The frequencies for the high-pitch bell cue has frequencies between 350–2500 Hz and the low-pitch bell has frequencies between 240–2000 Hz.

3.2 Sound Effects

Mainly two kinds of sounds were used: one kind for sounds that plays from all eight speakers, and another one for playing sounds that only comes from one speaker. Certain sound effects, like ambient music, were played from all speakers. However most sounds only needed to be played from one speaker and with a predetermined panning. The sounds were mapped to different speakers depending on where the source of sound is placed in the game environment, which reflected the actual position in the physical room. This sound mapping feature is key to make the gaming experience immersive.

The sound effects used solely to enhance the immersion of the game were: ambient background music, flickering light sounds, door opening sound. Sound effects that were used to guide the player were: background clock sound in Puzzle 3 and high- and low-pitch sounds in Puzzle 2.

3.3 Website UI Design

In order to control the game and input the puzzle codes, a website was created with HTML, CSS and JavaScript. The website essentially worked as a controller where the players' selected actions are reflected on the surrounding cylindrical display. The website was used for:

- Going in & out of puzzle rooms.
- Triggering the puzzles.
- Entering codes.
- Receiving hints to solve the puzzles.

The design was kept minimalistic with focus on quick reading and comprehension in order to not steal attention from the game environment and to prevent the players from looking for clues on the interface. The colour scheme was black, white and deep blue-green; the background being a gradient from black to blue-green and the text was white to contrast the darker background. A dark background was chosen to not distract the players with its brightness and be gentle to the eyes, considering that the room is kept dark it is also a factor to not light up the room.

The interface consists of clickable text, one or more textboxes for the code input, icons, a submit button and a trigger button, and every puzzle of the game has its own unique interface that differentiates from each other. The textboxes vary in size depending on input length, the input digits were restricted to 0–9 only, and the clickable text is highlighted when hovering to hint that they can click on it – see figure 3.8. Furthermore, input placeholders indicates how many digits the players need to enter – see figures 3.9, 3.10 and 3.11. Lastly, the positions of the puzzle names represents the location of the doors in the game – Puzzle 1 to the left, Puzzle 3 to the right, and Puzzle 2 in the middle across from the laptop – reflecting the room positions shown previously in figure 3.1.

Figure 3.8: The *control room* layout, also known as the *main room*. The mouse is hovering over the *Puzzle 2* text to hint that it can be clicked on.

On the Puzzle 2 and 3 pages there are icons added to the interface to the left of the input boxes. These are hints or guides to where the triggered clues in the game should be entered.

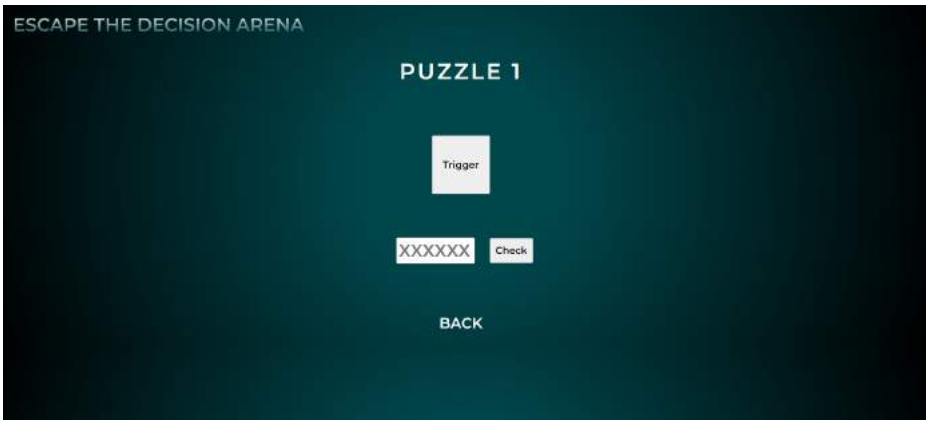


Figure 3.9: The *Puzzle 1* page layout.

Figure 3.10 shows two arrows, one tilting upwards and one tilting downwards to indicate high pitch input and low pitch input respectively. Arrows were chosen since they were the most universally understood icons and also humans often associate high pitch as a higher y-position [9]. Other candidates for representing high and low pitch were the treble clef and base clef, which are used in music notation, and sinus curves. Even animals were considered – for example a mosquito for high pitch and a lion for low pitch. However, they were all ruled out. The music notations would only be understood by those with a background in music, sinus curves are also only understood by those who has a background in wave and sound physics. They could perhaps have been used if the players had a background in music respectively engineering or were allowed to use the internet to search up their meanings, but the goal was to not use any external help and it should not be expected that the players have a background in certain areas in order to solve the puzzles.

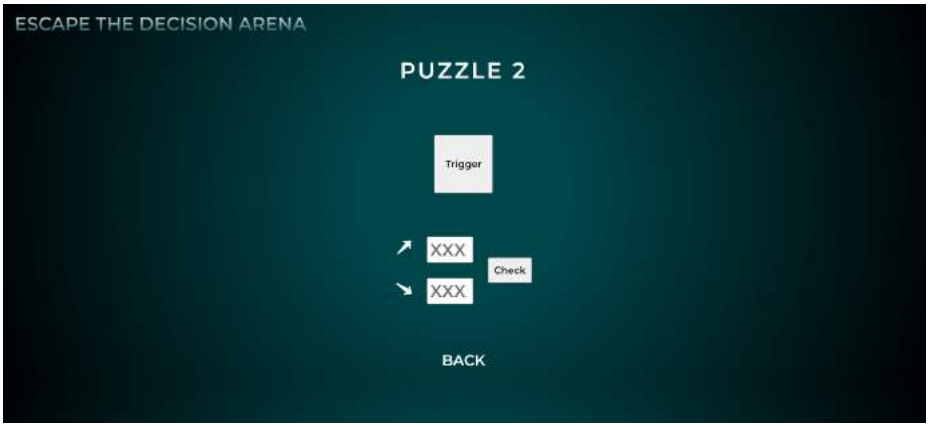


Figure 3.10: The *Puzzle 2* page layout. The up pointing arrow represents high pitch and the down pointing arrow represents low pitch.

In Puzzle 3 there are two other icons, one representing an eye and one a speaker – see figure 3.11. Since Puzzle 3 works with both visual clues and audio clues, these icons were the indication of that. The placeholder text "HH:MM" stands for hours and minutes respectively, hinting to the players that the solution to the puzzle is a digital time.

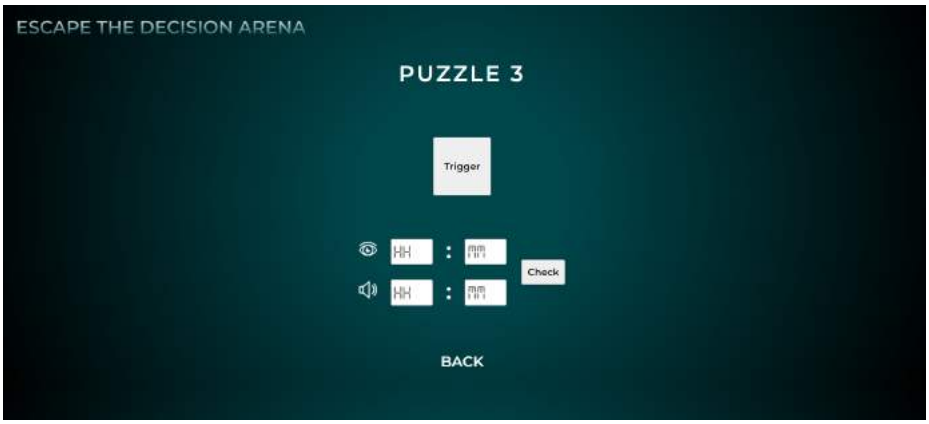


Figure 3.11: The *Puzzle 3* page layout. The upper row is the input for the visual clock, and the lower row is the input for the audio clock.

3.4 System Architecture

The overview of the system architecture is illustrated in figure 3.12. The player interacts with the game using the website on a laptop. The website sends the player input to a server, which is hosted locally on the same laptop, using WebSockets. The information is then sent from the server to Unreal Engine that is run on a desktop computer where the input is interpreted to an in-game action. Depending on the input, Unreal Engine will change the graphics on the cylindrical display and/or send a message to SuperCollider using OSC, which plays the sound associated with the message sent from Unreal Engine. The audio and graphics provide feedback for the player which helps the player with their next decision.

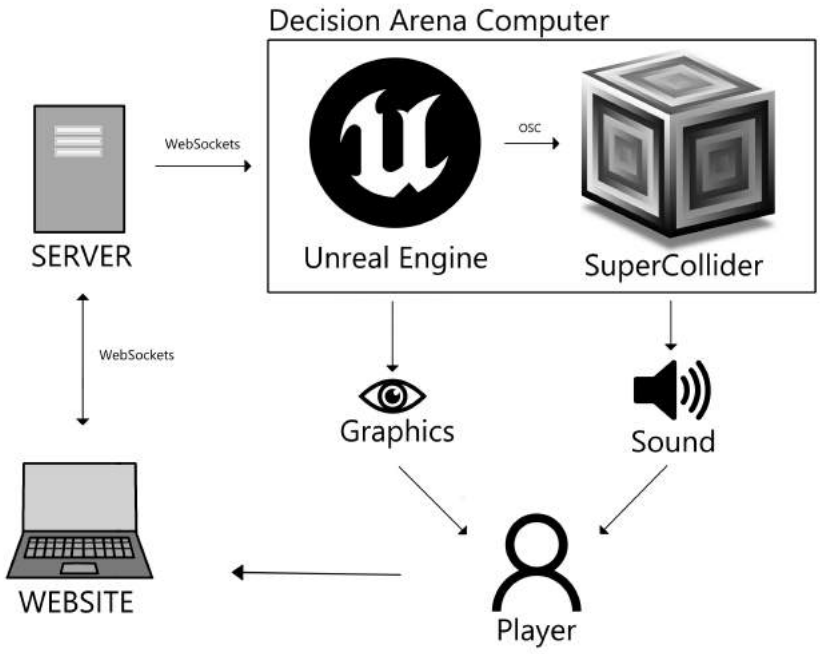


Figure 3.12: Illustrating the system architecture of the game.

3.4.1 Unreal Engine

Unreal Engine 4.27 was chosen as the game engine for the project of the thesis. Since games have never been developed for the Decision Arena and Unreal Engine is widely used[1], there is plenty of official documentation on Unreal Engine own website and help from various forums and developers. The engine also supports many different kinds of games, which makes the engine a safe choice when developing a game for an non-typical environment like the Decision Arena with little to no prior development and documentation of previous games. Unreal Engines Blueprints also enables implementation of game mechanics and functionality at a higher pace, compared with pure C++ coding.

3.4.2 Sound Implementation

Due to the uniqueness of the Decision Arena's environment and its surround sound system, audio became an essential part for the development. Sounds are used to guide the players through the game and to give them the solution for Puzzle 2 and 3. The point is to make use of the 360° environment to its fullest in order to achieve an immersive gaming experience. Initially, sound was going to be implemented with Unreal Engine. However, since Unreal Engine can only handle standard stereo sound format such as 7.1 and 5.1, which is not enough for the purpose of this thesis, a secondary software was chosen that could give the control and freedom needed to properly make use of the 8.0 sound system in the arena. Thus, all sound implementation was handled by the platform *SuperCollider* since it allowed total control of volume, placement, which individual speakers should be active, et cetera. In the contrary where Unreal Engine would risk playing sounds from the incorrect speakers – even if the sound is played correctly in the Decision Arena, the sound may blend between speakers which would make sound localization difficult – this problem does not occur in SuperCollider. It guarantees that the sounds are played discretely from every speaker and gives full control of the audio, which makes localization easier and ensures that sounds play exactly where it is intended to.

The audio used were all sound files which were manipulated to fit the game. For sounds with random panning, like the high- and low-pitch sounds in Puzzle 2, the panning was generated randomly in Unreal Engine and sent as a variable to SuperCollider. The correct panning was then calculated in SuperCollider to make sure that the sound came from the desired speaker.

3.4.3 WebSockets for Communication Between Devices

Since the game is controlled by a laptop and Unreal Engine is running on a separate desktop computer, a way to send messages from the website to Unreal Engine is needed in order to operate the game – this is where WebSockets are utilized. As mentioned in section 2.7, WebSockets can be used to communicate between a server and client, where in this case there are two clients – the website and Unreal Engine – that communicates with one server. A local server was set up using *node.js* using JavaScript. There were five unique interfaces in total: one for each respective puzzle, one for the control room, and one "START GAME" interface which when pressed triggers the WebSocket connection from the website to Unreal Engine.

In short, the connection works as follows: the website and server runs on the laptop and they communicate locally, and Unreal Engine on the desktop is connected to the server through the laptop's IP address via shared internet from a smartphone. The server works as a middleman between the website and Unreal Engine, meaning that a message from the

[1]The Best 7 Gaming Engines You Should Consider for 2022: https://www.incredibuild.com/blog/top-7-gaming-engines-you-should-consider-for-2020 (Fetched: 2022-08-05)

website first lands in the server, and from there it is sent forward to Unreal Engine.

In detail, a WebSocket in the JavaScript file was created at a localhost address with an arbitrary port. For connection between the server and the website, the same line was written in both the HTML files between script tags with the same port number. Messages through WebSockets were sent with a simple send-command in the form of *strings*. Using localhost worked for communicating between the server and the website since they were running on the laptop, however, in order to connect to the desktop that was running Unreal Engine another step had to be added.

When connecting two separate devices in such fashion, that connection is done over the Wi-Fi/internet. However the Wi-Fi in campus is public and blocks communication between devices. The block can be lifted through settings, though the connection risks not being safe due to the WiFi being shared between many devices. The solution was to share the internet from a smartphone device that both the desktop computer and the laptop connects to, which is safer since one can monitor which devices are connected to the phone's internet, though the connection is still blocked since it is public. One last step in order to make this connection possible was to change the settings of the laptop's firewall. The solution was to set "Secure Socket Tunneling Protocol" to 'public' and the devices could finally connect. Since the server runs on the laptop, the IP address of the laptop is used to connect a WebSocket from Unreal Engine to the server. As of now, no messages are sent back and forth between the website and Unreal Engine, only from the website to Unreal Engine. However, sending messages from Unreal Engine to the website is possible thanks to the WebSockets connection, though it was not further explored during the time of the thesis work.

3.5 Evaluation

To ensure quality and the level of immersion experienced of the game, user tests were conducted. The game was evaluated by a number of participants physically playing the game in the Decision Arena to ensure that accurate experiences were measured. Two rounds of pilot tests were held first during the design process, then 10 official tests were held for the final evaluation. Since collaboration is one key concept, the game was evaluated by pairs of participants playing the game while the developers were present in the arena to observe their group behaviour. Through the evaluations, the goal was to discover how well the game encouraged collaboration, if the game was fitting for two people, how much the players discussed the puzzles, how immersed they were, and see if the puzzles were challenging enough or too difficult. These were measured both by our observations, but also through a questionnaire and an oral interview where discussion was encouraged. Evaluating both qualitatively and quantitatively resulted in valuable feedback and insights which made it clear which aspects of the game were more difficult than expected, that not only could be used to answer our research questions, but also opened up many interesting discussion topics.

3.5.1 Evaluation Procedure

The game was evaluated in the Decision Arena by twelve pairs of testers, meaning that a total of 24 people participated in the user evaluation. All participants were in their 20s, majority were university students and some were university alumni, and all pairs were acquainted but one. It would have been interesting to study and compare friends versus strangers pairs to see if that would have had an impact on their collaboration experience and behaviour, which however was not explored due to time constraints.

They were first welcomed to the arena with an introduction from us and us thanking them for participating before preparing them for the test. They were told that they were

going to play a digital Escape Room game, though the details were kept at minimum so that they would go in with slim ideas on what is waiting for them. They were told to use a laptop to progress the game, to not use any other help besides themselves, and to only use their phones for important calls but not for taking notes. The players were told that there was a time limit, but did not specify how long they would play for since the players playtime would be measured and compared to what they personally felt like they played for, to see if they would experience any time distortion. Since the developers were going to sit in the same room but behind the screens, the players were asked to ignore the developers and not turn to them for validation during the test. The players were also told that it was not important how fast they were going to finish the game, instead that the experience of the game is what was important. After the the game was finished, the evaluation afterwards consisted of the players filling in a form and the developers interviewing the players about their experience. Lastly, the players were wished to have fun before the doors were opened into the game area.

3.5.2 Questionnaire

After the testers had finished the gameplay, they were given one questionnaire – or form – each to evaluate their experiences. The form consisted of a total of 18 statements, where the first few questions were yes/no replies and the rest were 1–5 Likert scale ratings. The purpose of the questionnaire was to gather numerical values to analyze and compare in order to find patterns to conclude what the average experience was – would the majority of testers have a similar experience, or would there be significant variations? Boxplots were used to analyze this quantitative data since it enables easy comparison, quick overview of the results and finding the outliers. A boxplot showcases the data using boxes, as the name suggests, where 50% of the data is inside a filled box and the remaining 50% is distributed between an upper and lower boundary. Furthermore, the average value of the data is represented by a cross. No open paragraph options were included in the form since people are less likely to motivate by hand, which is why the interviews were held as a complementary; this way a more even feedback would be gathered. The questionnaire statements are published in appendix A.

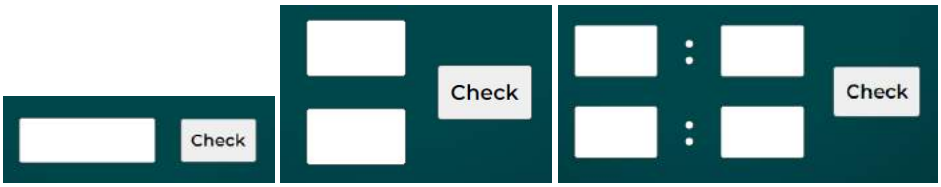
3.5.3 Interview

A structured interview was held following the questionnaire. While the questionnaire was individual, the interview was between the pair of participants together. The interview questions were connected to the questionnaire statements, but formulated in a way that engaged discussion. During the interview, follow-up questions could be asked in case the participants were confused or unsure what they felt, but also in case they would not elaborate further than a yes or no. If one would reply more than the other, the other player would be asked specifically for input before moving on to new questions. By holding interviews the participants were allowed to explain their train of thoughts, which was important for understanding what was possibly overlooked and how it could be improved. This qualitative data was gathered for valuable discussion points, picking out the statements that were either unique, interesting or common for all groups. The interview questions listed in appendix C were based on system immersion from section 2.1.1, engagement and engrossment as mentioned in section 2.1.2, and flow, cognitive absorption and presence which were elaborated in section 2.1.3.

3.5.4 Pilot Test Evaluations

First, two pilot tests were held in order to see how the process would play out, which interview questions were useful or missing, how long the test would take, and most importantly if the game was playable, too confusing or too easy. There was no time limit for the first pilot test to check how long it would take for them to finish. With our help it took them one hour to clear the game and almost one additional hour for the interview, which was double the

expected time. During the test it became evident what caused the confusion and the issues could be solved easily. First and foremost, the input bars initially did not have any placeholder text to visualize how many input digits were expected, see figures in 3.13. This caused the pair to discuss multiplying and adding the digits as a solution to Puzzle 1, which was not the idea of the puzzle. Having only a limit to the input digits and adjusting the length of the input bars to match the expected number of inputs, proved to not be sufficient in order to solve the puzzles. Furthermore, it became clear after this test which interview questions were redundant and which needed reformulation.

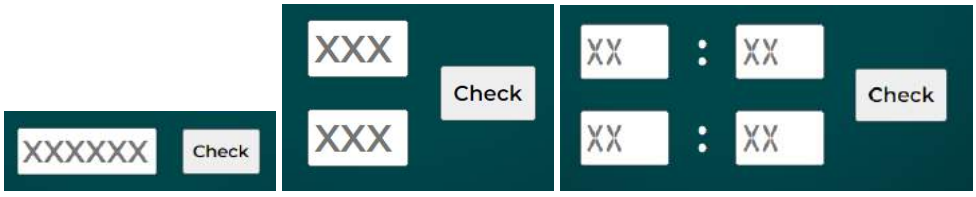


(a) (b) (c)

Figure 3.13: Puzzle 1–3 input boxes during the first pilot test.

For the next pilot test, it was decided to attempt keeping to a time frame of one hour; one half-hour for the gameplay and evaluation respectively. The puzzles were timed to 10 minutes each as well, working as an aid to when it was time to give clues. Timing the gameplay was later used to calculate the time taken to finish the puzzles and to measure time distortion experiences. Finally, the changes in the game that were done for the second pilot test were the following:

- Placeholder text for the input boxes for all puzzles.
- Text font changed to represent digital clock font for Puzzle 3, see figure 3.14(c).
- All input automatically deletes when pressing "Trigger" button.
- Added a clock ticking background sound effect in Puzzle 3.
- Raised volume for Puzzle 2 & 3 audio cues.
- Replaced clock sound cue to a longer sound in Puzzle 3.
- Started measuring the time it takes to finish each puzzle.



(a) (b) (c)

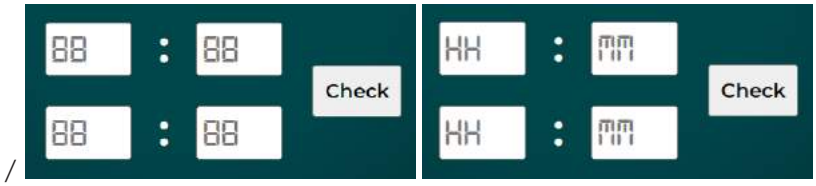
Figure 3.14: Puzzle 1–3 input boxes after the first pilot test, input placeholder added.

The second pilot test group finished the game within the time frame of 30 minutes and the placeholders proved to elevate the mechanics. They quickly acknowledged that Puzzle 3 was about a clock, the only problem was realizing the correct minute input. The placeholder got another rework after that and was changed from XX:XX to 88:88 to strengthen the representation of digital time input – see figure 3.14(c). It was considered here already to replace XX:XX

with HH:MM but suspected the puzzle would be too obvious with that solution. The new, longer clock sound cue for Puzzle 3 proved to be more difficult to localize than the shorter sound cue that the first pilot test used. This led to a change back to the original sound cue for the official tests. Finally, a wall-clock object was added to the Puzzle 3 environment and placed above the number 12 to make it noticeable. The clock has no minute- and hour-hands to avoid confusion since the players might think that they are a clue. In short, the changes that were made for the official tests were:

- Changed Puzzle 3 sound back to the original sound cue.
- Added a clock object in the scene above the number 12.
- Puzzle 3 placeholder input text changed from XX:XX to 88:88 – see figure 3.15(a).

After the first official test, the placeholder text was ultimately changed from 88:88 to HH:MM in Puzzle 3 after all since the participants were still confused over the minute translation – see figure 3.15(b). One last addition that was made during the official tests was to add a hint text for the Puzzle 2 and 3 interfaces. Since not everyone explored that the "Check" button could be used to check the code several times, only the "Trigger" button resets the code, a hint text was programmed to appear after the "Check" button had been pressed a certain number of times. The hint text reads: "Hint: You can use check several times, the code resets only when pressing 'Trigger'".



(a) (b)

Figure 3.15: Input boxes for Puzzle 3 after the pilot tests. The image to the left is what the placeholder looked like during the first official test. Right image is the input placeholder after the first official test.

4 Results

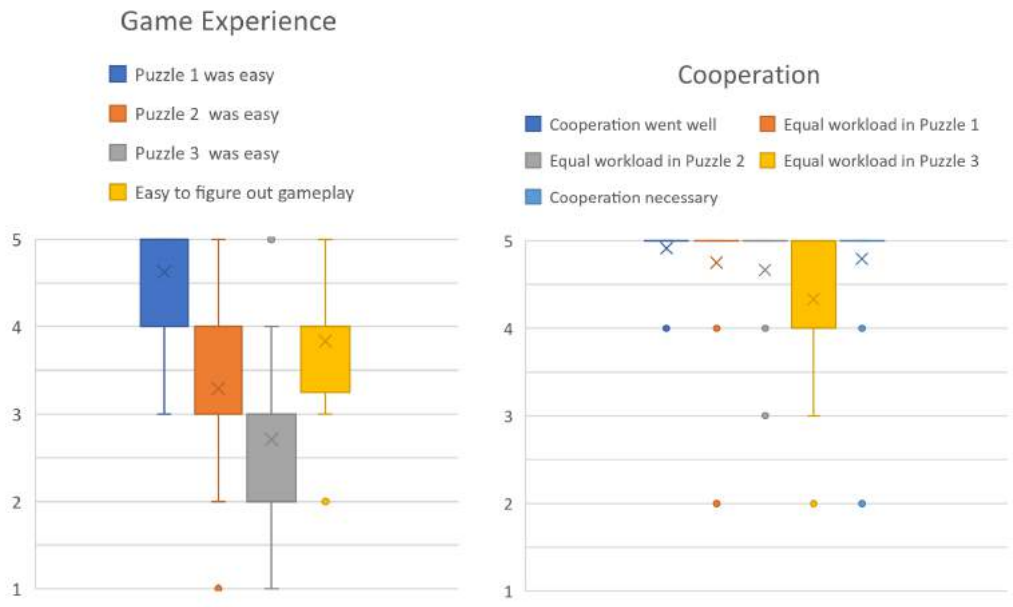
The results will be presented by the categories *gaming experience*, *UI* and *immersion*. In 4.1 the measured time for each test group can be viewed. In figures 4.1(a) and 4.1(b) the results from the user forms regarding game experience and cooperation is shown respectively. In figures 4.2 and 4.3 the results of the user form in regards to sound localization and UI & immersion is shown respectively.

Measured Time Table					
GROUPS	PUZZLE 1	PUZZLE 2	PUZZLE 3	TOTAL	GUESSED
PILOT TEST 1	-	-	-	>1h	-
PILOT TEST 2	2m 50s	10m 50s	10m 30s	24m 10s	30-40m
GROUP 1	30s	3m 50s	14m 55s	19m 15s	<15m
GROUP 2	1m 15s	7m 10s	8m 45s	17m 10s	20m
GROUP 3	1m 30s	9m 40s	11m 50s	23m	20-30m
GROUP 4	2m	5m 40s	13m 15s	20m 55s	12-16m
GROUP 5	1m	19m 40s	5m 15s	25m 55s	20-30m
GROUP 6	1m 40s	4m 30s	17m 10s	23m 20s	30-35m
GROUP 7	1m 20s	4m 30s	6m	11m 50s	15-20m
GROUP 8	1m 5s	2m 45s	6m 15s	10m 5s	15-20m
GROUP 9	1m 30s	17m 55s	5m 50s	25m 15s	20-30m
GROUP 10	1m 5s	2m 55s	17m 15s	21m 15s	30m
AVERAGE TIME:	1m 30s	7m 25s	10m 45s	20m 5s	24m 14s

Table 4.1: Table over measured time for each puzzle & average.

4.1 Game Experience

The 24 players gave the form question “I thought the game was easy to figure out” an average of 3.9 out of 5. In the interviews the players mentioned that they were able to quickly figure out how to play the game by navigating the website and how the puzzles worked. In the questions regarding the difficulty of the puzzles, show in figure 4.1(a), the players gave Puzzle 1 an average of 4.6 out of 5, Puzzle 2 an average of 3.2 out of 5 and Puzzle 3 an average of 2.7 out of 5. Overall the players mentioned that solving the puzzles in chronological order



(a) (b)

Figure 4.1: Results of game experience and cooperation from the questionnaire.

(from 1–3) made the puzzles seem gradually more difficult. 83% of players had played an Escape Room game before, however players who had previously played an Escape Room implied that their experience did not help that much to understand the game. Some even said that it rather made them overthink and search for clues and counting objects in the environment, thinking it was a part of the puzzle when it was not. Though, some mentioned that the problem-solving mindset needed for Escape Rooms helped slightly. Finally, players clarified that the game would have been possible to figure out even without the previous Escape Room knowledge.

The participants gave the form question "I felt that cooperation was necessary to complete the game" an average of 4.9 out of 5 as seen in figure 4.1(b), where 87.5 % of the players gave the question a 5 out of 5 – one player believed that the puzzles were solvable by oneself with enough practice. They gave the form question "I think the workload was equal between me and my co-player in Puzzle 2" an average of 4.8 out of 5, for Puzzle 3 the average was 4.3 out of 5. The players mentioned in the interviews that Puzzle 3 had less equal workload since localizing sounds was harder than looking at the cylindrical display for numbers.

4.1.1 Puzzle 1 Feedback Results

The test results for Puzzle 1 mostly lived up to expectation. 23 out of 24 players mentioned that cooperation was needed to figure out the code and that Puzzle 1 was a good introduction to the basic game mechanics. The average time for completing Puzzle 1 was 1m 30s, see table 4.1. They pointed out that Puzzle 1 was much easier than the other two, some thought it was too easy, though they added that it gave them confidence to solve the next puzzles. Most of them implied that its difficulty was perfect for an introduction to the game mechanics even if it was very simple.

The only hangup this puzzle got from the evaluation – which is a general flaw of the website – was that it was not obvious that players could move on to a new puzzle after

entering the correct code and getting a green light. Some instantly went back to the control room to change puzzle, though some mentioned that they expected the website to show that the puzzle was finished, and some expected the game to launch them back to the control room where they started after completing the puzzle. This resulted in some test pairs to stay in the room for a short while, replaying the puzzle a few times before concluding that nothing new was happening and they eventually tried to press "back" and moved on to a new room. However, as seen in table 4.1, it did not take long time at all for either of them to conclude that they could change puzzles.

4.1.2 Puzzle 2 Feedback Results

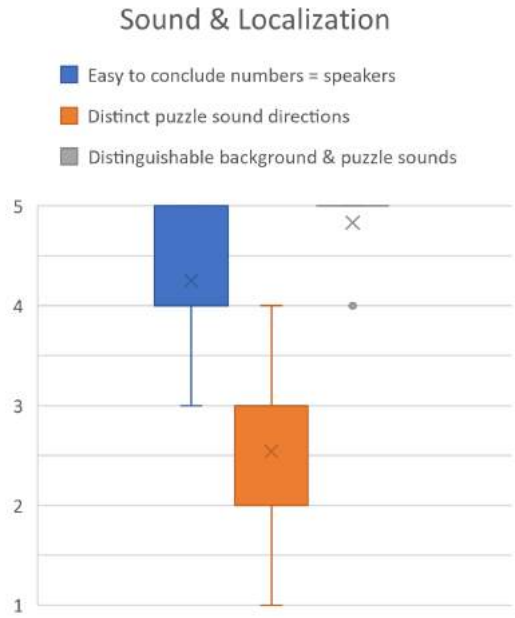


Figure 4.2: Result of sound localization from the questionnaire.

The difficulty has an apparent step up in Puzzle 2, as players gave the form question “I thought Puzzle 2 (audio puzzle) was easy to solve” an average of 3.2 out of 5 as seen in figure 4.1(a). The average time for solving Puzzle 2 as seen in table 4.1 was 7m 25s. Some participants said it was straightforward, some thought it was tricky at first, and some thought it was incredibly difficult. Most players interpreted the up- and down-arrows on the website (see figure 3.10) correctly as high- and low-pitch sounds. Although one group interpreted the icons as the lower and upper parts of the room, but they were still able to solve the puzzle because the sounds appeared, by luck, at the correct places the players were expecting.

Generally, the players quickly understood how to solve the puzzle. The form question “There was a clear distinction from which speaker the puzzle sounds came from” was given an average of 2.5 out of 5 as seen in figure 4.2, for example if the sound came from speaker 5 they were unsure if it came from speaker 5, 4 or 6, etc. All players mentioned that they had trouble with localizing the sounds and had to try multiple times to get the correct input, which was the main reason Puzzle 2 took longer to finish than Puzzle 1. Participants also mentioned that the high-pitch sound was easier to localize than the low-pitch sound, whereas someone mentioned that the low-pitch sound was easier. Some also tried out closing their eyes while listening to hear better and expressed that it was easier that way, and in the contrary some were confident that it was much easier to locate the sounds with open eyes.

In one of the tests, one of the players had impaired hearing which meant they were unable help their partner with sound localization. Instead the partner listened to all sounds and listed the numbers out loud for the other player with impaired hearing to type in to the website. Another interesting case was a group that started solving Puzzle 2, but they had so much trouble with localizing the sounds that they decided to leave Puzzle 2 to try solve Puzzle 1 and Puzzle 3 instead. They mentioned that Puzzle 3 was easier due to only having two sound cues, whereas Puzzle 2 was more difficult since they had to follow six sound cues.

Furthermore, a few observations were made regarding the players' positions in the room during the test. Some stayed at the same position during the entirety of the test, typically sitting by the laptop or both players standing across from each other on one side of the room. Those who split up on each side usually determined that they listen to one half of the room each and assigned specific speakers that they were going to listen to. They also switched seats, changing who was sitting by the laptop and the one standing on the opposite side. Amongst those who both tried to sit and walk around during the gameplay, some mentioned that it was easier to locate while standing up.

4.1.3 Puzzle 3 Feedback Results

The participants gave the form question "I thought Puzzle 3 (visual + audio puzzle) was easy to solve" an average of 2.7 out of 5, and the average time seen in table 4.1 was 10m 45s and they generally found Puzzle 3 to be the hardest. They picked up on the clock references quickly and that the solution was partly visual and auditory, but had once again trouble with the sound localization. 20 out of 24 players also mentioned that the sounds in Puzzle 3 were even harder to localize compared to Puzzle 2. Some players had trouble realizing that the solution to the puzzle was to read the numbers on the wall as a clock and translate the numbers into a digital time. Instead of translating the numbers into minutes, players would type in the numbers they saw directly on the cylindrical display as input, e.g. players would see number 11 at the hour-hand and number 3 at the minute-hand and then type in "11:03" when it should have been interpreted as quarter over eleven and typed in as "11:15". One player mentioned for Puzzle 3 that having a interactive clock on the website where you can turn the minute-hand and the hour-hand instead of text input could have been more intuitive.

Even though the players understood that the visual clock was separate from the audio clock, some of them experienced confusion since they expected that the visuals and the sounds would match up, thinking they would complement each other which contributed further to the puzzle's difficulty. Some participants mentioned that since the sound localization was so difficult, they started experiencing frustration and, in the worst cases, doubting if their understanding of the puzzle was correct. A few times the developers had to step in and confirm that the players indeed had understood the puzzle correctly, or hint to the minute input if that was the issue. At the same time, players also mentioned that Puzzle 3 was the most rewarding puzzle to solve since it was the most challenging.

4.2 UI

The participants gave the form question "I thought that the website interface (UI) was intuitive" an average of 4.5 out of 5, as seen in figure 4.3. They mentioned that the simple design worked in the favor of the environment since it did not draw much attention, however some did comment that the simplicity took them out of the immersion, saying that it felt out of place and that it was too simplistic compared to the environment that the game projected. Some players pointed out the lack of feedback from the website, for example when a puzzle was incorrect or cleared the website would give an indication on that – which would per-

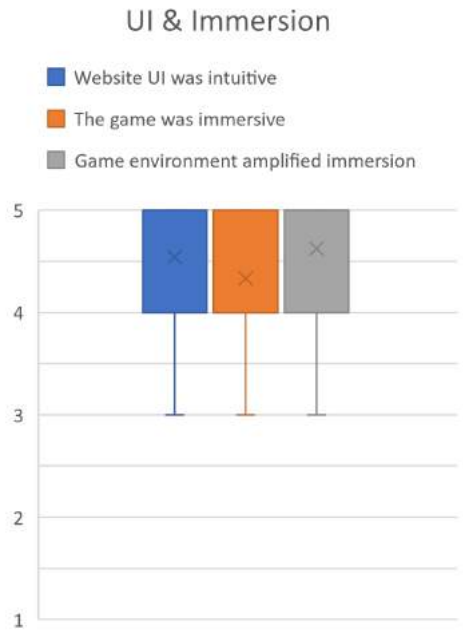


Figure 4.3: Results of UI & immersion from the questionnaire.

haps have saved time for some groups since they either were unsure if and when they could switch rooms. Since players had trouble localizing sound, they mentioned that feedback on the website would have helped with determining if their way of solving was lacking or if they just were unable to localize the sound well.

4.3 Immersion

The form question "I thought that the game was immersive" received an average of 4.3 out of 5 as seen in figure 4.3. During the interviews most players mentioned that they thought that the game was immersive in one way or another. The participants were also asked during the interview to guess for how long they were playing to see if they experienced some time distortion while playing – which they did as seen in table 4.1. On average they completed the game in 20 minutes and 5 seconds, and the average time guessed was 24 minutes and 14 seconds, meaning on average the players experienced a time distortion of 4 minutes and 9 seconds. Most participants experienced frustration while playing, mainly because of the sound localization, but majority also thought that the frustration pulled them into the game and made them want to solve the game even more. However, some mentioned that the frustration became too much after a certain amount of time, which made them feel unsure and started doubting themselves because they were unable to tell if they localized the sound wrong or if they had misunderstood the puzzle. This led to some players feeling that the game was luck-based since they had to try solving the puzzles many times with this uncertainty and hoping that they would eventually localize the sound correctly.

One player suggested that having a physical button to trigger the puzzle would have amplified the experience. Some participants realized that when they switched puzzles they went into a new room in the virtual environment, while some did not comment on it at all. They said that it would have been more immersive and clear if the doors had animations when changing rooms.

20 out of 24 participants mentioned that the environment enhanced the immersion and pulled them in more, giving the level of experienced immersion an average score of 4.3 according to figure 4.3. During the interview the participants did not leave any comments on the particle systems, sound effects nor flickering lights until we asked if they were distracting – which they implied were not. The exception was that some players thought the flickering lights in Puzzle 3 was distracting when they were looking at the 360 screen for the lit-up numbers.

5 Discussion

This chapter will discuss different aspects of the result, as well as reflecting on the methods used and thoughts on future work.

5.1 Results

One clear result from the evaluation is that most players thought that the sounds in Puzzle 2 and 3 were difficult to localize. Possible reasons for this could be that it is unusual to listen to more than standard stereo. The results also suggests that certain sounds are easier to localize in the Decision Arena than others, as most players found it easier to localize the sounds from Puzzle 2 than the Puzzle 3 ones. Specifically, in Puzzle 2 most players thought that the high-pitch sound was easier to localize than the low-pitch sound. One possible explanation for this is that the high-pitch sound has frequencies between 700–5000 Hz which means that there are optimal frequencies for both of our sound localization systems, ITD and ILD, as mentioned in section 2.2.1. While the low-pitch sound has frequencies between 220–2850 Hz, meaning that there are only frequencies optimal for ITD according to M. Risoud [22], therefore ILD can not be used to its fullest which makes the sound more difficult to localize. That same possible explanation can be applied to why the sounds were harder to localize in Puzzle 3, since the high-pitch bell sound has frequencies between 350–2500 Hz and the low-pitch bell sound has frequencies between 240–2000 Hz. Another reason could be that the structure and/or room acoustics of the Decision Arena may affect how certain frequencies or sounds are perceived.

Majority of participants reported that the difficulty of the puzzles gradually increased which was also a desired goal. However, they also commented that Puzzle 3 was too hard, or that the difficulty gap from Puzzle 2 to 3 was too big. One of the main reasons for this gap was that in Puzzle 3 the players tended to struggle with "translating" the numbers to digital time. One possible reason to why this was a problem could be that the players were primed by Puzzle 1 and 2, meaning that they learned to type in the numbers they saw on the cylindrical display directly as the solution in Puzzle 1 and 2. However, in Puzzle 3 this thinking worked against the players since they had to translate the numbers on the clock into hours and minutes, and the problems always occurred with the minute input. In hindsight most participants expressed that it was obvious that they needed to translate the numbers

to digital time, but since the players had learned from the previous puzzles to type in the numbers directly, this puzzle broke the pattern and therefore made it harder to figure out. One group suggested adding another puzzle between 2 and 3 that prepared the players for this interpretation of numbers like Puzzle 3 has.

Even though many participants found Puzzle 3 to be frustrating because of the sound localization and difficulty of translating the numbers, they reported consistently that solving Puzzle 3 was more rewarding than solving Puzzle 1 and 2. This suggests that the frustration draws the players into the game to a certain extent, though it must be noted that too much frustration takes them out of the experience.

One group mentioned that Puzzle 1 was too easy and suggested that the numbers should also change position in the room every time they light up – as of now the numbers appear on the same spot every time. This idea also allows the users to look around more in the room, which is a great usage of the screen space, at the same time raises the difficulty level slightly without making it too confusing as the first step of the game.

The idea was to design the puzzles to be difficult enough that they were only solvable with two players. Initially, Puzzle 2 and 3 worked slightly different than the final version; the high- and low-pitch sound cues were at first going to play at the same time, not high-pitch first and low-pitch after, which turned out to be too difficult. Technically, Puzzle 2 and 3 are possible to solve by only one person with enough practice. However, according to the test results the participants still thought that the puzzles were only solvable with two players despite the reduced difficulty, which means that the sense of cooperation was still evoked in the game. This suggests that a game of similar kind does not actually have to be strictly solvable with two players only, it simply needs to be difficult enough such that the game feels overwhelming for one player to complete the first time they play within a set time limit.

5.2 Method

Because the sound localization ended up being more difficult than expected, doing a pre-study to explore which sounds are easier or harder to localize would have been beneficial. This could have eased the difficulty of the sound puzzles since almost every participant mentioned how challenging it was. One could argue that difficult sound localization is a part of the challenge that comes with playing the game. However, since some players felt the game became luck-based because of the sound localization, which was not a desired goal, this became a problem which could be solved with more knowledge of how sound works in the Decision Arena.

The website interface generally received positive feedback. One comment that was often mentioned was that the website could have given more feedback during the gameplay, since as explained in 3.4.3, the website is currently unable to provide with any feedback as it is not implemented in Unreal Engine to send messages to the server. This two-way communication is already possible thanks to WebSockets, though a feedback system needs to be implemented in Unreal Engine in order to send messages back to the website. One example of useful feedback could be confirming which digits are correct if the players checks for a solution in any of the puzzles, similar to the game *Wordle* [1]. Every correct digit on the website would turn to the color green and every wrong digit would get the color red.

Furthermore, some participants mentioned that the website interface is too minimalistic and does not match the game concept. They suggested that a retro computer style with a

[1] Wordle: www.nytimes.com/ (Fetched: 2022-06-29)

black background and green or gray digital font would have been a better choice of aesthetic, which in hindsight makes more sense. No study on the interface itself was conducted to see how intuitive it is just by itself without making any interactions with the game. One interesting suggestion from a player was that the trigger button could have been a physical button, commenting that it would have enhanced the immersion. The idea is interesting and we agree on that it could have made the game more engaging and maybe even more memorable. Another comment was that the trigger button could have been red or in some other colour than white plus a different shape than square, which might have made players more aware of it since some tried to solve the puzzle without triggering because they did not think it was the key to trigger the puzzle.

Continuing on the topic of the website, there was also some confusion about the method of solving the puzzles for some participants. Since the website does not provide any feedback, and since localizing sound proved to be difficult for some participants that they failed several times because of it, they started doubting their method of solving even if they had the correct theory. For example, when some groups in Puzzle 2 started doubting that their theory of low and high frequencies was the correct way of solving, they started speculating around other possible solutions which were incorrect. A way to give subtle hints depending on input and the number of incorrect answers would have provided the players with more security in their theories, or if they get stuck because they have not figured out the puzzle at all.

Access to the Decision Arena was given later into the project process than expected. This led us to exploring how to set up the actual gaming environment in Unreal Engine later, where different methods were researched and considered but ultimately ended up not being necessary – some of them are mentioned in 5.3. Because of the delayed access, the game had to be developed on our own computers meanwhile; the problem being that there is a big difference between developing for a standard, flat screen and for a cylindrical display. The most challenging and difficult part was to picture how big or small the objects in the scene had to be, how the lighting in the virtual room would become, and not to mention the sound functionality. One way around the scene designing part was to apply markings on the plane wall to indicate the top, bottom, left and right of the wall area that the cylindrical display captures.

The initial idea was to have user evaluations earlier in the developing process, then have a week or two to adjust the game according to the feedback, followed by a final evaluation of the complete game. Though, the developing process was longer than expected due to incorporating a website and having to set up WebSockets, which in turn led to changing the project from a Blueprint-based project to a C++ based one, plus finding a solution to the 8.0 sound system since the engine turned out to be unable to handle any other output than stereo. The evaluations were still useful for our research questions, though it would have been interesting to compare a before and after difference.

In general, working with Unreal Engine was rewarding and straightforward once the basics were learned. However, working with lighting turned out to be more tedious than expected. In Unreal Engine, usually the lighting in the scene needs to be built in order to make the light and surroundings to appear more detailed and create shadows. Shadows was one problem that occurred, where some objects did not cast shadows and some did. The reason is still a mystery so we decided to remove the objects that did not cast shadows. We noticed that the scene would look strange when the lighting was built, and the light we wanted to appear after a certain trigger was built in the scene even though it should be invisible. This led to light sources having to be removed, then the light was built again, and then putting the light sources back into the scene without building the light again.

One last note is that sometimes there is noticeable delay between sound and light in the scene. For example when a puzzle fails, the sound could be one second faster than the red light. This is due to how Blueprints are constructed as the files do not compile as fast as C++ code, meaning that there is a delay factor to count in. Since us both were new to using Blueprints, perhaps the visual scripting code was constructed in an inefficient way which caused the delay, however there was not enough time to dive deeper into this issue.

5.3 Alternative Methods

This section discusses some alternative methods for the thesis which were considered but were scrapped in the end as other, more fitting solutions were found.

5.3.1 Second Viewport Alt. 1

Instead of using a website and server to communicate with the game engine, a second viewport used directly in Unreal Engine was considered. The idea was to split the game screen and the interactive interface screen to two separate windows, and use a HDMI cable between the computers to move over the second screen to a laptop and control the interface from there. This way, the UI would have been developed in Unreal Engine and using servers would not have been needed. While researching this solution, a second-screen plugin was found that worked for Unreal Engine 4.26 whereas the version used for this thesis was version 4.27. The plugin was tested anyways, but this second screen ended up only working for the editing mode of Unreal and not during play mode – and for having a gameplay it was necessary to run the game in play mode. For this reason, it was decided that this solution was insufficient.

5.3.2 Second Viewport Alt. 2

When concluding that the second viewport plugin would not work out, research into multiplayer implementation in Unreal Engine began. This would allow to start several instances of a game, meaning that one instance would be a window for the gameplay itself, and one window would be for the interactive interface to control the game. However, the implementation would be more complicated than to simply creating a website and connecting it to Unreal Engine, since multiplayer implementation covers clients, servers and updating all the logic and variables between the clients which would make the programming process more tedious than it needs to be.

5.3.3 TCP plugin & Communication Protocols

In the early development stage, the Unreal project was Blueprint based and solution for Blueprints were mainly explored and tested. Plugins for connecting Unreal Engine to a website locally needed to be downloaded as they were not available in the Blueprint standard library. The *TCP Socket Plugin* is a free plugin that was tested for this purpose, which however only resulted in a successful connection but messages would not be sent nor received between the website and Unreal Engine. After some research it appeared that C++ files were necessary for creating a WebSocket communication, which was the chosen solution in the end. The plugin *Blueprint WebSockets* was added to the marketplace shortly after the C++ WebSocket files were already implemented which would have made a WebSocket implementation entirely in Blueprints possible. Furthermore, the *VaRest Plugin* could be used to handle HTTP requests – it was however not free to download. Though, VaRest is a popular method for server communication and probably would have worked as an alternative. Unreal Engine also supports sending messages between applications through JSON Queries but was not utilized for the purpose of this thesis since simple strings were sufficient, but could be used to send more detailed information from the website.

6 Conclusion

The goal of this thesis was to explore a way to utilize the Decision Arena, which resulted in a two-player, immersive digital Escape Room game that we called "Escape the Decision Arena". The game is unique and customized to that particular environment due to the number of speakers, and the resolution and physical measurements of the cylindrical display. Through user evaluations we were able to establish the fact that the game was challenging enough for two players, encouraged collaboration, and immersed the players with its mechanics and sound effects, as well as gave us enough information to answer our research questions.

6.1 Research Questions

- What are the benefits of utilizing a cylindrical display when creating a collaborative gaming experience in the Decision arena?

  The game was designed in a way that utilized the fact that one player cannot see the whole cylindrical screen at once, which was used as one key factor in the collaboration aspect; the players were essentially forced to cooperate due to this. This was further confirmed after the evaluations as they all realized early into the gameplay that they needed to work together in order to solve the puzzles.

- What game logic and mechanics will encourage a collaborative gaming experience in the Decision Arena?

  Even though Puzzle 2 and Puzzle 3 technically are solvable by one person, the game intentionally overwhelms the players with information to force collaboration by making the players divide the work required to solve the puzzles. This is further supported by the results from the evaluation, where the feedback of the question "*I felt that collaboration was necessary to complete the game*" got an average rating score of 4.9 out of 5. Since the puzzles randomly generates new codes each time they are triggered – and players can trigger the puzzles as many times as they want – the players have to rely on their own memory and trial-and-error until they succeed in solving the puzzles.

- What are the design considerations in terms of sound, visuals and interaction that contributes to an immersive experience when developing a game in the Decision Arena?

  The surround sound system was an important feature to achieve immersion which was utilized by having the players localizing sound cues coming from all directions of the room. The players generally found it difficult to localize the sound in both Puzzle 2 and Puzzle 3. Most players thought the sound localization in Puzzle 2 was easier, where the high pitch sound was the easiest, whereas the reverbed clock-sounds from Puzzle 3 were both perceived as difficult. This suggests that certain types of sounds and pitch in the Decision Arena are easier to localize than others.

  The goal with the in-game visuals was to create an eerie ambience which made the players feel trapped inside an industrial-like environment. Darkness, dust particles and flickering lights were used to achieve that ambience of an abandoned setting. Aside the quality of the 3D models, the immersive experience overall would have been better if the physical environment had been altered to match the environment in the game, as some participants pointed out. For future work, finding a way to utilize the table and make it a part of the game would erase the fact that it is a hindrance.

  Interaction with the laptop's UI received positive feedback such that it was intuitive and easy to use. However, some participants expressed that the design of the website did not match well with the aesthetics of the game since it had a minimalistic design, which ultimately took them out of the immersion. A retro design would have been a better choice in regards to the immersion aspect. Furthermore, the website lacked progress feedback since messages were only sent from the website to Unreal Engine and not vice-versa. Feedback could have been used to effectively guide the players when they seem stuck on a puzzle instead of us intervening which would break them out of immersion. Lastly, the possibility to use physical buttons as a way to trigger puzzles and switch rooms would have been a beneficial addition to the immersive experience.

A Form Questions

Do you know your co-player well? (friends/co-workers/acquainted) *

- ◯ Yes
- ◯ No

Are you a casual gamer? (All types of games are valid: TV, console, computer, mobile games, boardgames, etc.) *

- ◯ Yes
- ◯ No

Have you played an Escape Room before, or the alike? *

- ◯ Yes
- ◯ No

Section 1/3: Gaming Experience & Cooperation

I think it was easy to figure out how to play the game *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I thought Puzzle 1 (visual puzzle) was easy to solve *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I thought Puzzle 2 (audio puzzle) was easy to solve *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I thought Puzzle 3 (visual + audio puzzle) was easy to solve *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

The cooperation between me and my co-player went well *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I think the workload was equal between me and my co-player in Puzzle 1 *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I think the workload was equal between me and my co-player in Puzzle 2 *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I think the workload was equal between me and my co-player in Puzzle 3 *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

I thought cooperation was necessary to complete the game *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

Section 2/3: Visuals, Sound & UI Interaction

It was easy to distinguish between background noise and the puzzle sounds *

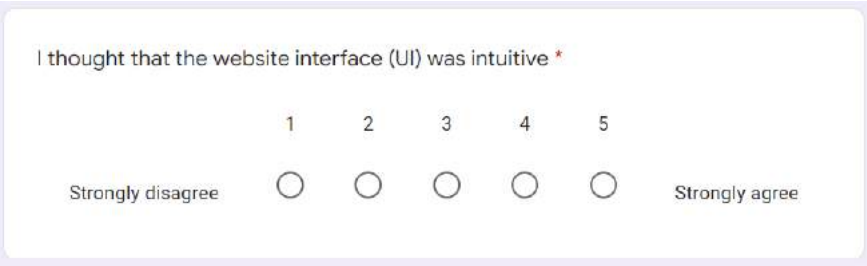
	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

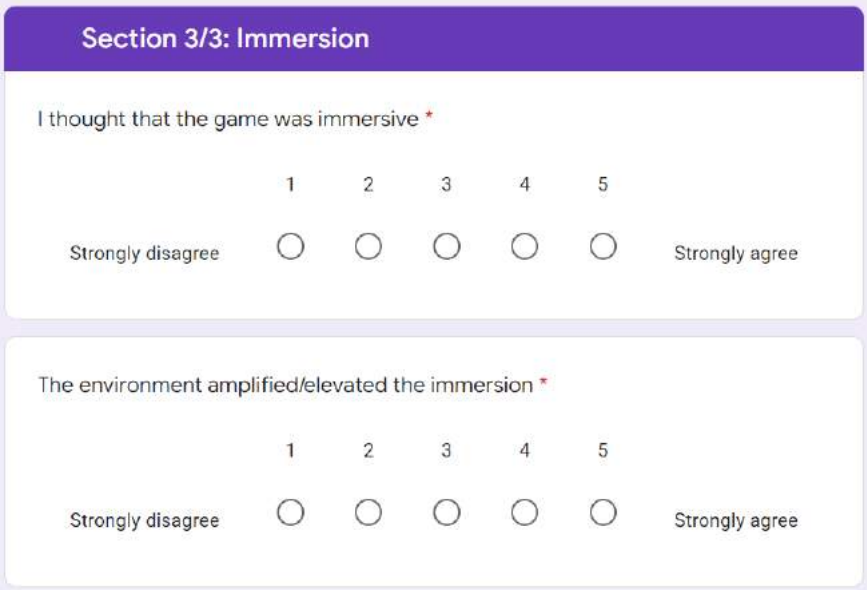
There was a clear distinction from which speaker the puzzle sounds came from *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree

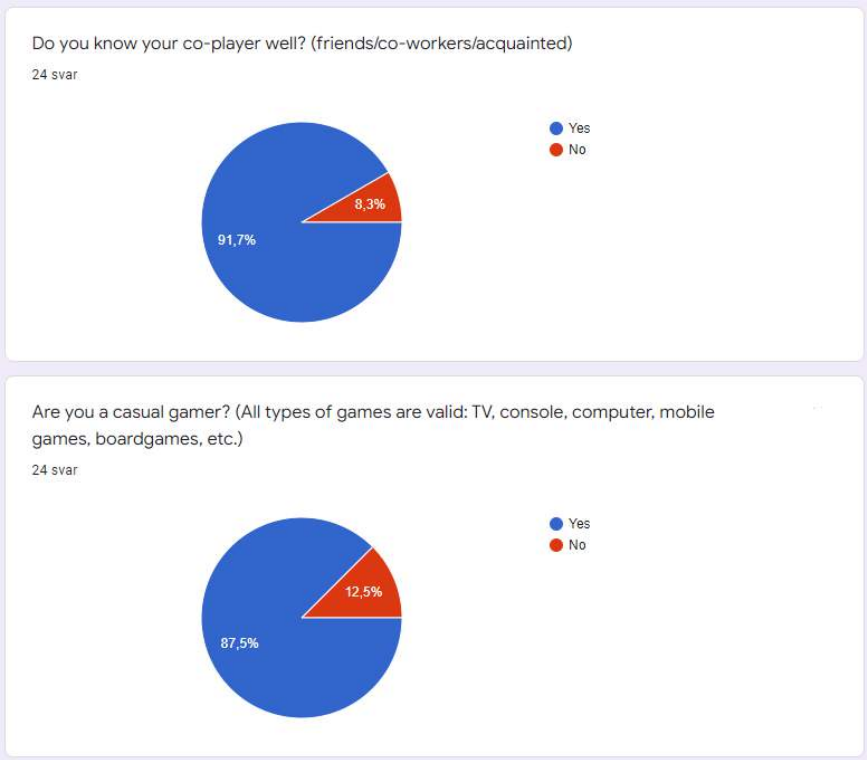
It was easy to conclude that the numbers correlated to the speakers *

	1	2	3	4	5	
Strongly disagree	○	○	○	○	○	Strongly agree


I thought that the website interface (UI) was intuitive *
1 2 3 4 5
Strongly disagree
Strongly agree


Section 3/3: Immersion
I thought that the game was immersive *
1 2 3 4 5
Strongly disagree
Strongly agree
The environment amplified/elevated the immersion *
1 2 3 4 5
Strongly disagree
Strongly agree

B Form Conclusion



Have you played an Escape Room before, or the alike?

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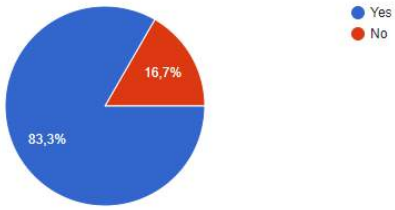

Section 1/3: Gaming Experience & Cooperation

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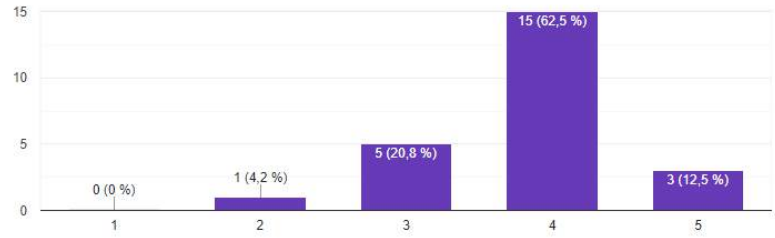

I thought Puzzle 1 (visual puzzle) was easy to solve

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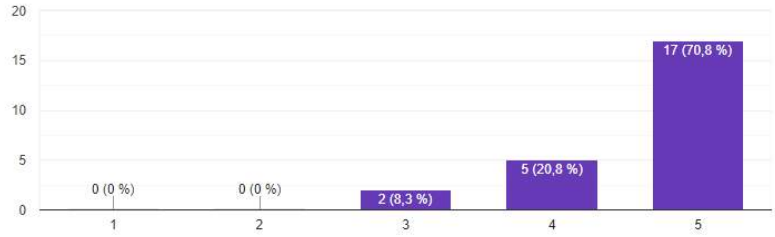

I thought Puzzle 2 (audio puzzle) was easy to solve

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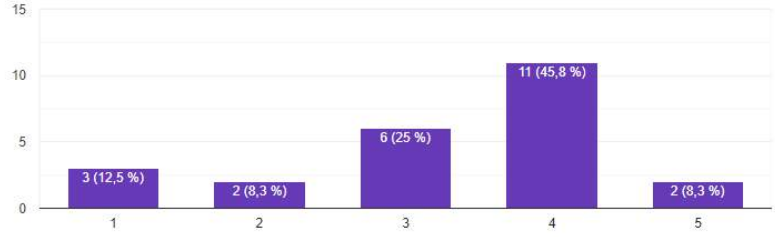

I thought Puzzle 3 (visual + audio puzzle) was easy to solve

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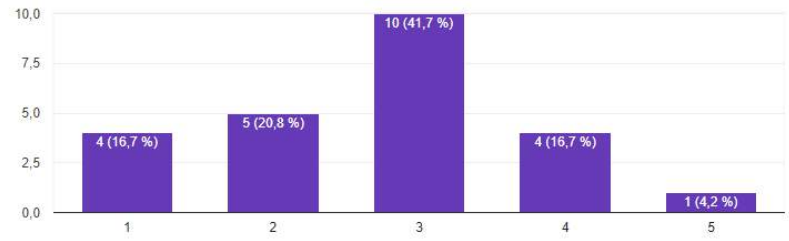

The cooperation between me and my co-player went well

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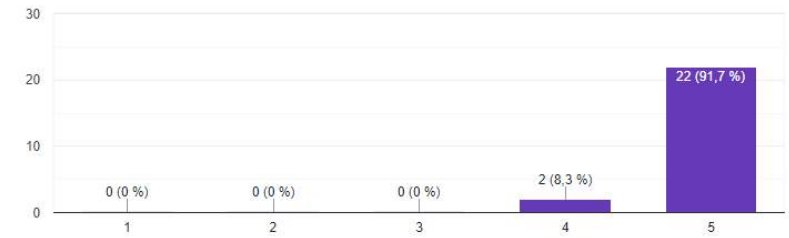

I think the workload was equal between me and my co-player in Puzzle 1

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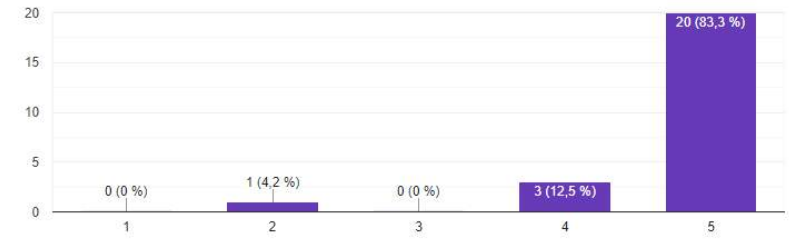

I think the workload was equal between me and my co-player in Puzzle 2

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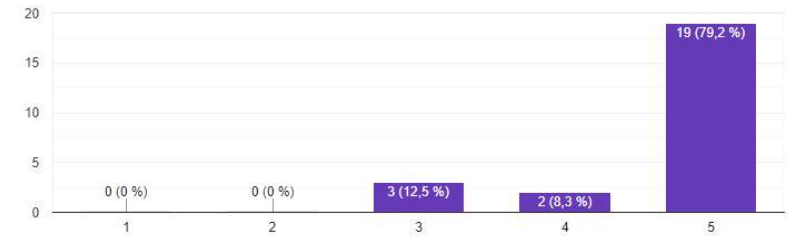

I think the workload was equal between me and my co-player in Puzzle 3

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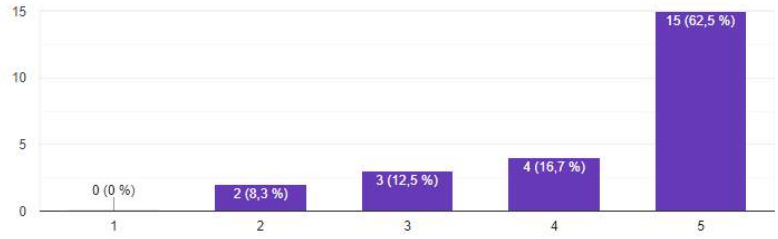

I thought cooperation was necessary to complete the game

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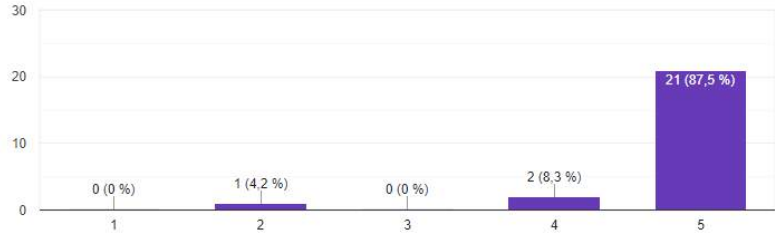
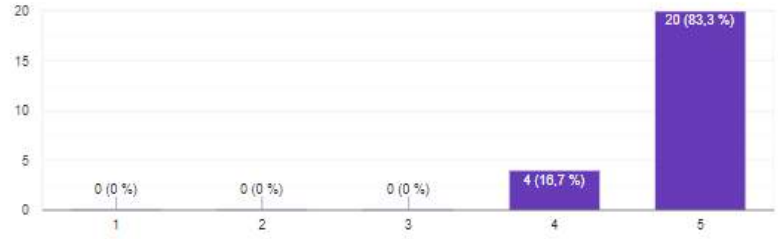


Section 2/3: Sound & UI Interaction

It was easy to distinguish between background noise and the puzzle sounds

Kopiera

24 svar



There was a clear distinction from which speaker the puzzle sounds came from

Kopiera

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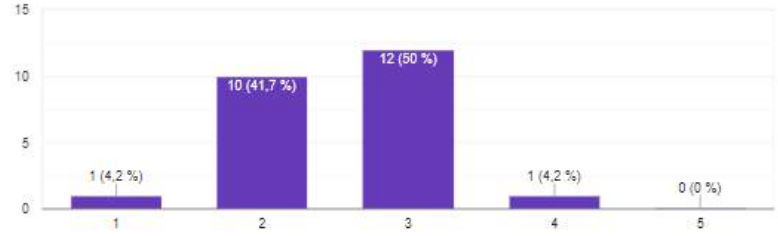

It was easy to conclude that the numbers correlated to the speakers

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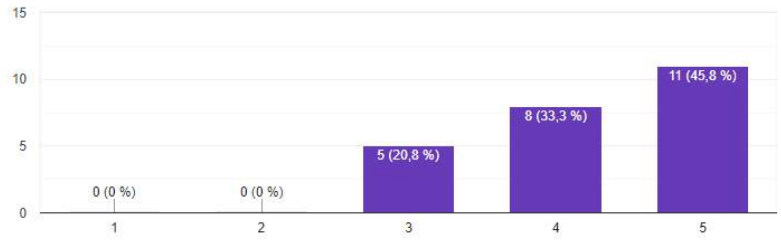

I thought that the website interface (UI) was intuitive

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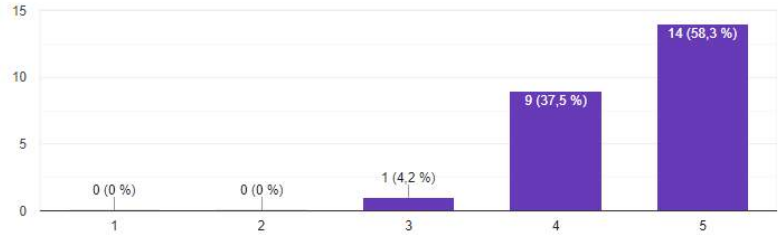

Section 3/3: Immersion

I thought that the game was immersive

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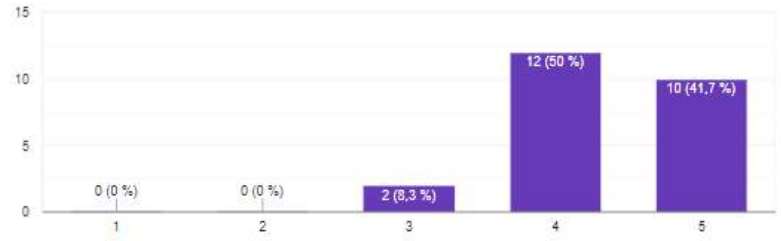
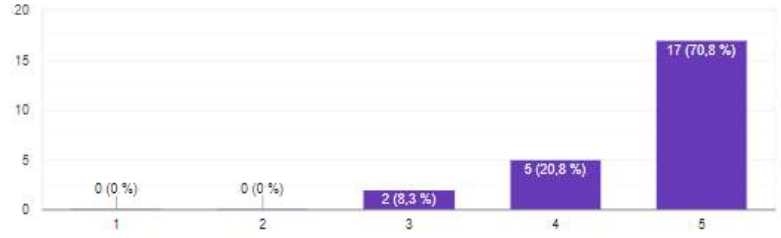


The environment amplified/elevated the immersion

24 svar



C Interview Questions

SECTION 1: Game experience & cooperation
GAME EXPERIENCE:
(See form: crossed yes on previous Escape Room experience) We see that you have prior experience of Escape Rooms. Would you say that your experience helped solving the puzzles?
How was it to figure out how the game worked?
What are your thoughts on puzzle 1, which was the wall-code puzzle?
What are your thoughts on puzzle 2, which was the sound-puzzle?
What are your thoughts on puzzle 3, which was the mixed puzzle with audio and visual clues?
Do you think the puzzles should be more difficult or easier?
Was it rewarding to complete the puzzles?

COOPERATION:
Do you think cooperation was necessary to complete the puzzles?
Did you think the cooperation between you went well?

SECTION 2: Audio & UI interaction
AUDIO:
How was it to localize the sound that gave the code for puzzle 2?
How was it to localize the sound that gave the code for puzzle 3?
Was it easy to distinguish between the puzzle sound and background sound?
Was the echo in the room disturbing or distracting?

INTERACTION / USER INTERFACE:
What did you generally think of controlling the game with a laptop?
Did you think that the website was responsive? Did it react in a way you expected?
(Show puzzle 2 web page) How did you interpret the icons?
(Show puzzle 3 web page) How did you interpret the icons?
What did you think of the website UI?
Any particular aspects that were unintuitive?

SECTION 3: Immersion, Sound-Effects & Environment
IMMERSION:
Did you find the game immersive by your own understanding or definition?
Did you feel that the game was something you were experiencing or engaged in, rather than just doing an evaluation?
How long did it feel like you were playing the game for?
Did you feel like you lost track of time while playing?
Did you feel like the game separated you from reality?
Did it feel like you thought less of your everyday concerns? Did you momentarily forget any upcoming tasks to do after this?
Did you feel a will to complete the game?
How would you have felt if we forced you to quit mid-game and not let you finish the game?
Did you feel any frustration when solving the puzzles?
Did you feel that the frustration amplified the immersive experience, or ruined it?

SOUND-EFFECTS:
Any opinions on what the sound-effects contributed to the game? Did you even notice them? Which ones in that case?
Do you think the sound contributed to the immersion or do you rather think it ruined the experience?

VISUALS / ENVIRONMENT:
Looking only at the environment, where do you think the game is located?
Did the environment ignite feelings in you? If yes, which ones?
There were different particle systems in this environment *(explain which ones)*. What are your thoughts on them, if you noticed them?
Did they elevate the experience? Or were they distracting?
There are flickering lights in the environment. What were your thoughts on them?
Do you think that they contributed to the immersion? Or were they distracting?

FUTURE WORK:
Do you think that this kind of game is fitting for an environment like the Decision Arena?
Do you think that this game could be used for team-building purposes?

GENERAL COMMENTS:
Any general thoughts or comments to add that we haven't brought up yet?

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