Electronics and IT
Aalborg University
http://www.aau.dk

Title:
An engaging Serious Game made with BIM simulating fire evacuation safety practice training for university students.

Keywords:
Serious Games; BIM, Evacuation Behavior; Wayfinding Behavior; Engagement; Player Enjoyment; Evacuation Practice; User Engagement Scale; Simulation;

Project Period:
Spring Semester 2024

Project Group:
MED10-08

Participant(s):
Frederik Kort Bønnelycke Høimark
Johan Slobodziuk Olsen
Martin Moeskjær

Supervisor(s):
Thomas Bjørner

Copies: 1 **Page Numbers:** 36

Date of Completion:
Friday 24th May, 2024

Abstract:

This project investigates engagement and informing university students about evacuation safety practices through a realistic virtual fire evacuation simulator. The created application is a first-person serious game, that simulates a fire evacuation in a realistic location using BIM to construct a realistic 3D environment, with typical evacuation scenarios based on theoretical evacuation behaviors. 57 within-group participants were used for a pre/post-test knowledge assessment questionnaire comparison and a post-test engagement questionnaire. This data was supplemented with data collected from the game, including choices made during evacuation and time taken to evacuate. The data was not normally distributed, and the game proved to be sufficiently engaging with positively skewed results. Learning outcomes were generally positive though one of the six success criteria was not met, with the knowledge question associated requiring a re-evaluation. Unforeseen implementation of BIM of a building plan following safety guidelines made decision-making and risk-taking easier for the player than expected, when always given the choice of taking the stairs or taking the elevator, resulting in a lack of experience when participants were asked not to use an elevator in the knowledge assessment questionnaire. The research question "Can a serious game be engaging and used to improve the knowledge about fire evacuation procedures at a university campus?" was considered a success with five out of 6 success criteria achieved. Potential further research into smaller, more focused simulations rather than a single, larger simulation as done in the project.

Contents

1 Introduction

With large buildings, there is the risk of potential fire or terror emergencies that can happen while many people reside within. For a long time, traditional training methods for evacuation purposes have been in use but have been reported not to be effective learning methods (Feng, González, Amor, Lovreglio, & Cabrera-Guerrero, 2018). Those traditional training methods can be a series of images or a paper introducing multiple-choice scenarios for each pivotal decision a person can make during an evacuation. It has been reported that most accidents and injuries are caused by not following official evacuation practices, and which practices to authorize in different situations (Lin, Zhu, Li, & Becerik-Gerber, 2020), (Proulx & Reid, 2006). This emphasizes how critical that knowledge is regarding how to behave during emergency evacuations.

Behaviors, seen in emergencies, range from how people perceive imminent danger and know there is an evacuation, to wayfinding through an environment with other people to an exit (Kinsey, Gwynne, Kuligowski, & Kinateder, 2019), (Kobes, Helsloot, de Vries, & Post, 2010), (Lin et al., 2020). People may also have motives for not evacuating immediately (Thompson & Wales, 2015). Traditional methods of providing instructions in a written format have been reported to be less efficient than multimodal media, such as video instructions - both when it comes to becoming knowledgeable in the long term, and the general sentiment from the users (Bloch & Bloch, 2013), (Schnellinger et al., 2010).

It was found that in some situations, text was more convenient to find information quickly through skimming compared to video. However, this was at the expense of its effectiveness in terms of the level of comprehension (Alexander, 2013). One should also consider the mediums' advantages and disadvantages, and how multimodalities play a part in a user's level of comprehension (Alexander, 2013).

AAU-CPH and current evacuation warning methods: Aalborg University Copenhagen, referred to as AAU-CPH, is a university campus operated by Aalborg University in Copenhagen, Denmark. All of Aalborg University's educational and research activities in the Greater Copenhagen area are based here. The three buildings, located at Teglholmen, are a former Nokia research & development center. AAU-CPH offers 10 undergraduate programs (bachelor's degrees) and 24 Master graduate programs (master's degrees), both within the fields of natural sciences and humanities. Aalborg University Copenhagen has approximately 4,000 students and 600 employees across three buildings.

There are written manuals for evacuation instructions at Aalborg University Copenhagen (AAU-CPH). In some cases, the instructions are open to interpretation and may not achieve the desired level of comprehension. The instructions dictate that only staff may take action to lead an evacuation. According to a meeting with the facility management at AAU-CPH both staff and students are allowed to take action with an evacuation. Not achieving clear instructions or the comprehension of a user like a student or staff, seems like an oversight of where you may demand multimodal media to assist the instruction materials. In particular, when someone like a student or staff is most likely to cause additional accidents (Proulx & Reid, 2006).

Hovedstadens Beredskab (The Capital Emergency Response) has different guides depending on each institution's circumstances, overall, they offer four methods for which they have created guides that can be downloaded on their website. [1] The three methods, which are within scope, focus mostly on how the institution's warning systems and their reporting of the fire, which should be done according to what the individual institution has (Hovedstadens-Beredskab, 2024).

[1] In Danish: `https://hbr.dk/brand-og-evakueringsinstrukser/`

The guide relevant to this project is the guide made with the assumption that the building has an ABA(Automatic fire reporting system) system and an automatic warning system activated by the ABA once a fire is detected or discovered. According to Hovedstadens Beredskab, this would be the case for newer institutions, schools, assembly halls, etc (Hovedstadens-Beredskab, 2024), which the AAU-CPH campus is.

Apart from these guides, Hovedstadens Beredskab has a general guideline that can be followed. This guideline, however, only informs what to do if a fire is found, but not how to prepare for that eventuality except for conducting physical exercises (Hovedstadens-Beredskab, 2024). Their guide follows these four steps roughly if a fire is found: 1; Dial emergency services, 2; How to warn others in the building, 3; How do you ensure that others have gotten out, and 4; What to do, if you can't get out. It is made clear that depending on the space and type of institution you are in there may be different fire and evacuation guidelines to follow (Hovedstadens-Beredskab, 2024).

Introducing more multimodal training content could help increase the level of comprehension and potentially mitigate the number of accidents during evacuations. One possible direction to make multimodal evacuation training content beyond just video animation is the development of serious games (Bjørner et al., 2023), (Carvalho, Ranauro, De Abreu Mol, Jatoba, & Legey de Siqueira, 2022), (Feng et al., 2018), (Yang, Xu, Wu, Wei, & Song, 2021). A serious game is a game genre with a purpose beyond entertainment but contains crucial, typically educational information within the entertainment medium of games. Several serious games for various evacuation training have already been made but vary in purpose, target groups, and platforms (Chen & Chien, 2022), (Feng et al., 2018). It may be possible to convey the same instruction segments in serious games and introduce instructions to the user through creative use of attention, engagement, and surprises. This allows for effective information conveyance to an engaged user to facilitate long-term knowledge for someone like a student or staff at a university (Zhonggen, 2019).

This study is based on the following research question:

Can a serious game be engaging and used to improve the knowledge about fire evacuation procedures at a university campus?

%	**Success Criteria**
70	Are engaged with a combined mean score of above 3.75
90	Know how to evacuate during a fire
70	Know not to use an elevator during a fire
70	Know always to try to take the shortest unblocked route to an emergency exit
90	Recognize the alarm warning about a fire evacuation
70	Know the color of the evacuation leader's vest when an evacuation is active

Table 1: Success criteria used in this project.

2 Analysis

2.1 Previous Work

Other serious games regarding evacuation are dominated by the overall intent of minimizing the risk of injuries and death in case of a fire in a public setting. This ranges from offices to schools, with the most common environment being serious games simulated within a university setting (Carvalho et al., 2022), (Bourhim & Cherkaoui, 2020), (Menzemer, Ronchi, Karsten, Gwynne, & Frederiksen, 2023), (Sacfung, Sookhanaphibarn, & Choensawat, 2014), (Silva, Almeida, Rossetti, & Leca Coelho, 2013), (Yang et al., 2021).

Most serious games about evacuations focus on the general practice of safety protocols in an immersive setting. They are measured either by self-evaluation, a knowledge test to verify learning through the game, by the number of correct actions taken within the simulation, or by the general time it took the trainee to evacuate the building (Carvalho et al., 2022), (Chen & Chien, 2022), (Sacfung et al., 2014), (Yang et al., 2021).

The minority of the studies cover realistic simulated environments through Building Information Modelling (BIM) to achieve a more believable experience (Rüppel & Schatz, 2011), (Sacfung et al., 2014). In contrast, other studies try to emulate the environment by hand, (Carvalho et al., 2022), (Chen & Chien, 2022), (Yang et al., 2021),(Wolf & Teizer, 2022).

A notable issue in these kinds of studies is the lack of clarity within the methodologies used, the need for data to be further analyzed, and the projects being evaluated to require more realism to achieve a better sense of presence and predictive behavior (Chen & Chien, 2022), (Menzemer et al., 2023), (Silva et al., 2013), (Wolf & Teizer, 2022).

Methodologies are often presented as general pre-existing guidelines similar to real-environment drills, just directly converted to a game-environment drill instead. However, the studies do not seem to base the tasks of an objective with the focus on underlying human behavioral theories that would happen in case of a fire emergency, as they stay pragmatic and in some cases true to the existing emergency practices in their local area (Bourhim & Cherkaoui, 2020), (Carvalho et al., 2022), (Chen & Chien, 2022), (Menzemer et al., 2023), (Sacfung et al., 2014), (Silva et al., 2013), (Yang et al., 2021), (Wolf & Teizer, 2022).

In general, the reception of the serious games made by those studies is that they are invaluable tools, but are not meant to replace the existing fire evacuation training (Carvalho et al., 2022), (Chen & Chien, 2022), (Sacfung et al., 2014), (Silva et al., 2013), (Yang et al., 2021). Based on several studies, developing, and evaluating fire evacuation simulators should ideally contain an immersive setting and gameplay, exercising some safety protocols evaluated on knowledge assessment questions, self-evaluating questionnaires, and logged gameplay performance such as interior navigation and choices made within the game. Some theoretical and practical background as to why some safety protocols are the way that they are would benefit in bringing further clarity to the implementation of scenarios suited for the safety protocols, and how to log the gameplay data.

2.2 Evacuation Practices at AAU-CPH

Aalborg University (the overall organization) has a general plan that covers all campuses (AAU, 2019) and a local plan for each campus(AAU-Copenhagen, 2023). For this project, the local plan for the campus is employed as a basis for the knowledge participants need to gain. The local evacuation plan contains the different types of warnings that one might encounter. The three types of warnings are explained as, **1;** using loudspeakers informing that something has happened in a local area, it is used to guide people. **2;** Tonewarning, is using tones to inform that one should leave the area since it is no longer safe. **3;** Warning by yelling, if one discovers it is no longer safe to be in an area a person yells to make people aware that they should leave the area. It states that evacuation must happen if a building is no longer safe and the automatic warning system must be activated (AAU-Copenhagen, 2023). It is not explicitly stated if there's an ABA system in place, but it mentions that by pressing the fire alarm the automatic warning system is activated and the fire brigade is dialed. However, during a conversation with the facility management from AAU-CPH, they informed there are ABA systems in place in every room at AAU-CPH. As per AAU-CPH's internal evacuation plan, it is the employees' own volition to act and evacuate during an emergency. When an evacuation is necessary, two roles are to be undertaken: The evacuation leader and the gathering place leader. Each role requires a unique vest and a guide outlining the responsibilities. For this project, only the evacuation leader is considered relevant, due to the gathering place leader role mainly involving post-evacuation. It is worth mentioning that in situations where a teacher is teaching, they are responsible for acting as the evacuation leader for their students. In the event of a fire, the discoverer of the fire must limit the fire, if it is safe to do so. Fighting the fire is only recommended if it is safe and with the appropriate equipment for different types of fires (AAU-Copenhagen, 2023). This is the case for both students and staff. Students are not mentioned in the local emergency plan, only staff is mentioned (AAU-Copenhagen, 2023). In an interview with the facility management at AAU-CPH, they disclosed that it is expected that both students and staff can take on the roles of evacuation and assembly leader. In case of an emergency, having a clear and well-defined evacuation and firefighting plan is crucial. However, the current emergency response plan for AAU-CPH is lacking in certain areas, which leaves room for interpretation. For instance, students are not given any responsibility in case of a fire, and it is unclear what they should do apart from following directions. There is also no guidance on whether they should fight the fire or evacuate, nor are there any instructions on distinguishing what type of firefighting equipment to use, when it is safe to use, or whether to press the fire alarm. There is also no guidance on what to do if a teacher isn't present to take responsibility for the two roles of the leader.

It can be concluded that the identification and role of an evacuation leader is important. The route that people take to evacuate is important as is the knowledge about the areas that the person is in. The overall concept of the evacuation alarm and what to do once it is active is important, especially since some routes may be more intuitive to take but not the fastest.

2.3 Behavioral Theories

In some aspects, serious games are no different from ordinary games regarding how they would integrate a game's narrative into game mechanics. One narrative feature in these simulations that could be integrated as a mechanic to evoke surprises is to promote events based on various behaviors under emergency evacuations and challenge the trainee (Zhonggen, 2019). By challenging typical behavioral theories, trainees can gain a deeper understanding of emergency procedures. This not only enhances the player's knowledge but also helps them become more self-aware of their behaviors. This awareness can prevent players from violating emergency procedures due to personal ideals or demeanor that may go against the guidelines they have been taught. A way of categorizing several facets of behaviors met during emergencies is separating them into "pre-evacuation behavior", "wayfinding behavior", "interactive behavior with others", and "interactive behavior with the environment" (Lin et al., 2020).

Pre-evacuation behavior Pre-evacuation behavior is during the early stages of decision-making and taking action. It can be before people realize that they have to evacuate, understanding that it is not a drill, or even knowing the severity of the situation that will come moments after (Proulx & Reid, 2006), (Lin et al., 2020). Empirically data has shown that pre-evacuation behavior can set an evacuation back by hours (Kinsey et al., 2019).

Wayfinding behavior Other behaviors, like wayfinding behaviors, are under the context of the heuristics involved when navigating to the exit under an evacuation (Lin et al., 2020). It is about navigating under pressure, may that be through layout familiarity, and the complications of stress tampering with cognitive processes (Kobes et al., 2010), (Lin et al., 2020). When smoke is introduced, many signs, such as exit signs, are paid significantly less attention (Kobes et al., 2010).

Interactive behavior with others During emergency evacuations, people usually evacuate in groups and interact with each other (Lin et al., 2020). This interaction may involve individuals taking on specific roles, helping those needing assistance, and dealing with various emotions that arise due to the stressful situation. These emotions can range from altruism, where individuals act in the best interest of others, to competitiveness, where individuals may feel the need to compete for resources or attention. All of these factors contribute to the overall experience of an evacuation (Kobes et al., 2010), (Lin et al., 2020). For instance, in a tall building, some co-workers would prioritize helping disabled people out of the building at a rapid pace (Proulx & Reid, 2006). Note, that this is not limited to disabled people but anyone needing assistance evacuating.

Interactive behavior with the environment Lastly, interactive behavior with the environment is the decision-making and risk-taking involved in navigating through hazardous environments or retrieving and protecting property from a given hazard by either evacuating with said property or containing the hazard directly (Thompson & Wales, 2015), (Lin et al., 2020). An instance, as mentioned previously, some of the co-workers helping disabled people out of a larger building risked taking the elevator, although it is normally seen as something that shouldn't be risked (Proulx & Reid, 2006). It should be noted that the three categorizations of human behavior under emergency conditions are not always distinct from one another, as certain themes may overlap. One paper has explored this topic, examining various facets of human behavior in a detailed manner and linking them to each of the aforementioned categorizations (Lin et al., 2020). Looking at the behavioral theories, it is possible to investigate the individual behavioral elements presented and break down further the individual behavioral aspects of emergency evacuations. A visualization of where the individual behavioral aspects are affected can be seen below in figure 1.

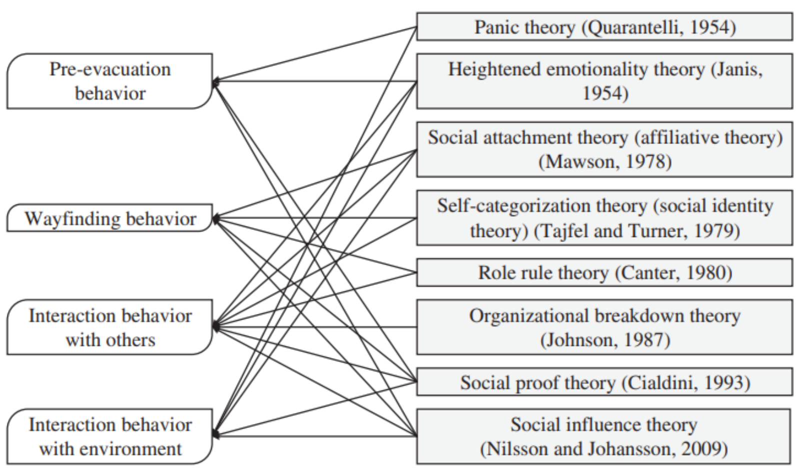

Figure 1: Visualization of relevant topics related to the four overall topics of emergency evacuations (Lin et al., 2020).

Type of response	Description
Panic	Under emergencies, it is typical behavior to experience someone undergoing immense distress and start acting out on core fight or flight instincts which can contribute to the chaos in an already distressing situation. (Quarantelli, 1954)
Heightened emotionality	Similarly to panic, this is less focused on the instinctual part of human behavior but more on the heightened sense of emotions that can be overwhelming and cause emotionally driven decisions or suffer cognitively based on your current level of stress Kobes et al. (2010), Janis (n.d.)
Self-categorization	In the moment of knowing a friend or a stranger, there the intergroup categorizations, whether you are in a friend group, or outside of a friend group, you may experience different behaviors or perhaps develop a fear of abandonment should they not trust you, etc. (Hogg & Reid, 2006).
Role rule	In contrast to the intergroup categorization, roles make certain patterns, based on social roles, per-event actions, and together role rules. Based on roles a pattern can be made for the human behavior, and assist in simulations to make more efficient evacuation plans (Canter, 1980), (Chu & Law, 2019).
Organizational breakdown	In contrast to forming roles, a crisis may inflict social disorder, promote aggression, and selfishness, and similarly to picking up an authority position, may start competitive behavior. The idea is that having a social structure will mitigate any sort of disorder (Lin et al., 2020).

Table 2: Relevant emergency evacuation topics for individual evacuation behavior

These types of responses from table 2 could potentially aid in creating some context-related game mechanics when designing the serious game. This context-relation could make game mechanics and education work together. Instead of working as separate entities unrelated to one another. This gives more room for the potential creative freedom to make a more engaging experience.

2.4 Serious Game Design for fire evacuation and disaster management

Serious games enjoyment and surprise mechanics Using player enjoyment (Sweetser & Wyeth, 2005), (Sweetser, 2021) there's the potential to increase the engagement of players. Player Enjoyment contains different elements, and not all elements can be implemented in the design of a serious game. Regarding the element of Challenge, this might not necessarily be desired in a serious game, as it could potentially interfere with the learning goals, regarding increasing and adding challenge. As the serious game's primary function would be to educate, most of the challenge will likely be based on the user's knowledge and should assume that players have little to no prior knowledge. The social interaction element is not likely to apply to this project, as multiplayer or social communities outside of the game are beyond, the scope of the project. The increase in engagement together with surprises should allow for better learning retention.

Surprises in serious games have been shown to create an increase in learning retention when players were exposed to a sudden increase in their cognitive load through the effects of a surprise that was not expected as per the rules of the game (Bjørner et al., 2023). By using player enjoyment (Sweetser & Wyeth, 2005), (Sweetser, 2021) together with the principles of surprise the learning effect could be improved.

Serious Game Design for fire evacuation Serious games to teach fire evacuation have been created where different goals have been set, and different methods were used to reinforce the learning and detect if players did learn anything from it. It is common for serious games to focus on the time and route that players take. Some games focus on repetition to learn and enforce the learnings, while also focusing on hazard avoidance through the use of NPCs (Non-playable characters) (Yang et al., 2021). Results showed that players did increase their safety scores, a score that was calculated at the end of the game, for each of their playthroughs (Yang et al., 2021). Serious games can be designed and implemented with a rule-based design that allows elementary schoolchildren to learn about evacuation practices

(Carvalho et al., 2022) without having to go through a real-life scenario. By design, rules were used as guides to follow and the players were then asked to go against these rules. If they choose to do so, they fail in their task. This choice of design contrasts with the players' model of how the game should be played since they learn that even if they are asked to do something that is against the standard procedures and rules they will fail (Carvalho et al., 2022).

Measuring the players' knowledge before and after also helps with eliminating doubt as to what their base knowledge was and is. This is beneficial due to how self-reported measures can be affected by bias when it is measured directly after playing the game. Several serious games mimic real-life places (Yang et al., 2021), (Carvalho et al., 2022), some are more direct in their approach to mimic real-life places at universities (Sacfung et al., 2014).

Common for fire evacuation is that they tend to work with known locations and have themes that use local rules for evacuation. Often are the games based on rules that dictate what can and cannot be done within the confines of the game. If players were informed of their choices being wrong, they would correct themselves (Sacfung et al., 2014). This gives reason to believe that if players are informed of their choices being wrong, and the reason for them being wrong, it can increase their retention further.

Different training methods of evacuation practices through literature (Menzemer et al., 2023) found that modern technology is prevalent in evacuation training where immersion, engagement, and realism would positively affect the learning if an increase in the aforementioned themes was possible (Menzemer et al., 2023).

Most of the literature suggests that serious games are the most prevalent method of teaching evacuation training where often a public setting is used as the 3D environment. It is also noteworthy that serious gaames increase engagement and awareness by allowing players to explore and experience the consequences of their choices in a safe environment (Menzemer et al., 2023).

Disaster management serious games To evaluate the players' game different methods have been used, from self-reported measures (Bjørner et al., 2023), granted not an evacuation type game, however, the method can still give an insight into methods for which obtaining player's self-reported measure.

Measuring the steps taken during an evacuation down to their interaction with the environment (Silva et al., 2013) and summative scores at the end of playing with repeated playthroughs (Yang et al., 2021), basing the serious game on rules in stages where players are confronted with choices that ultimately would lead them to fail where a pre and post questionnaire was used to detect if the game was successful in improving knowledge (Carvalho et al., 2022). Some results indicate that there isn't a relationship between players who are knowledgeable and not regarding the environment that the serious game takes place in (Sacfung et al., 2014). This is however not something that all researchers agree on (Daylamani-Zad, Spyridonis, & Al-Khafaaji, 2022). Knowing the building layout may give faster decision times, resulting in more immediate action. This gives reason to believe, that if the game is designed effectively and players have concise instructions regarding the evacuation, it doesn't matter if they know the internals of the building they evacuate from. However, there is also evidence for the opposite.

Results indicate that there is a correlation between in-game and real-life evacuation time. Players can learn to evacuate efficiently and if the 3D environment is transferable to the real world, knowledge can be conveyed that can be crucial to the evacuation (Sacfung et al., 2014).

Overall we see that serious games have been made and that it is possible to transfer knowledge from a serious game to the real world with comparable results. Likewise, it is possible to reliably and efficiently measure participants' learning through self-reported measures but also measures that are not visible to the players.

2.5 Success Criteria

This study has integrated current recommended emergency plans from Hovedstadens Beredskab and local emergency plans from AAU-CPH with behavioral theories and knowledge on the design of serious games. Drawing on a review of relevant literature and expert knowledge from Hovedstadens-Beredskab, we have devised a set of criteria that must be met to define our artifact as having achieved sufficient learning. These criteria serve as design pillars that, must be reflected in the artifact as seen in table 6. From left to right the percentages that are deemed a success, the success criteria, how it should be implemented, the theory on which it is based, and the knowledge assessment questions the success criteria are reflected in.

%	**ID: Success Criteria**	**Implementation**	**Theory**	**Test Questions**
70	SC1: Are engaged with a combined mean score of above 3.75	Game "Flow"; Enjoyment criteria	(Sweetser & Wyeth, 2005)	UES-sf inspired questions
90	SC2: Know how to evacuate during a fire	Players are given a debriefing at the end of the game informing them regarding their choices during the evacuation.	Wayfinding behavior	Q1, can be seen in table 6
70	SC3: Know not to use an elevator during a fire	Taking an elevator in the game will lead to a "loss" but evacuation will still take place.	Interactive behavior with the environment	Q2, can be seen in table 6.
70	SC4: Know always to try to take the shortest unblocked route to an emergency exit	Multiple routes the player can choose within the map. Only the shortest route results in a "win".	Pre-evacuation behavior, Wayfinding behavior	Q1 and Q3, can be seen in table 6
90	SC5: Recognize the alarm warning about a fire evacuation	Use real alarm sounds from AAU-CPH and implement cues relating to fires.	Pre-evacuation behavior	Q1, can be seen in table 6
70	SC6: Know the color of the evacuation leader's vest when an evacuation is active	The player is informed of the correct color when receiving their game evaluation.	Game evaluation at the end of playing (Carvalho et al., 2022).	Q4, can be seen in table 6.

Table 3: The knowledge assessment questions can be seen in chapter 5 table 6

3 Design

The game was designed based on the principles of game enjoyment, supplemented by surprise as seen in Table 4, and behavioral theories in Table 5. Social interaction from game enjoyment was not considered for this project, as there is no multiplayer, and the dialog within the game is not considered to fulfill this requirement; social interaction should not be confused with interaction behavior with others from behavior theories.

Game Design Principle	**Design**
Concentration	The game contains text-based prompts and audio cues within the environment, to help hold the player's attention and direct the player.
Challenge	The game simulates a fire evacuation and contains realistic and believable scenarios that can occur during an evacuation. The game is also objective-based, with tasks the player must complete in sequential order.
Player skill and controls	All players, regardless of game experience, should be able to play the game without much difficulty. Therefore, the game is a simple first-person game, which uses industry-standard, first-person controls. Dialog and interactions are done via the left mouse button or the E key. When the player looks at interactable objects a text popup containing these controls also appears.
Clear goals	In the top left corner of the screen, the player's current task is shown. When the player completes the current task, it is updated to a new task. The tasks are used to guide the player through the game. An evacuation plan detailing the level that the player can look at and signs and icons placed around the level marking escape routes and certain rooms also help to guide the players to find their way around.
Feedback	Interactable objects have both a sound and visual cue when the player interacts with them. The current task for the player is visible in the top left corner of the screen. Furthermore, at the end of the game, the player is given a debriefing regarding their choices during the game. The debriefing informs the player about why certain behaviors during a fire evacuation are correct. Should the player make an incorrect choice, the debriefing will also inform the player why the choice is incorrect and what the correct choice should have been.
Immersion	The game level imitates a hallway based on the AAU CPH campus. Sounds present in the game, also mimic what an expected real sound would make for the corresponding object. The evacuation alarm is also the real evacuation alarm used by the AAU CPH campus.
Surprise	The evacuation alarm happens during a mundane task the player will be performing shortly after the game starts. The player is also questioned by an NPC firefighter after they have evacuated based on the responsibilities of an evacuation leader, a role the player has not been informed about nor has actively taken. There is also an NPC student whom the player can help during the evacuation but is not directly informed about this possibility.

Table 4: Game design principles applying to the game, and how they were implemented.

Much like the game design principles, Behavior Theory is similarly applied, based on the work mentioned in chapter 2.3 with the idea that developing certain elements and mechanics could help stimulate real evacuation behavior from the player. The design is not randomly chosen but picked from previous serious games about navigating interior buildings, evacuation procedures, and detecting hazards from chapter 2.4.

Behavior Theory	Design
Pre-evacuation Behavior	As you are finishing your task of printing out paper, an alarm will go off out of nowhere and you have to figure out how to evacuate by yourself after hearing the announcement.
Wayfinding Behavior	The game simulates a campus corridor, constructed through BIM based on old campus building plans from a CAD file distributed from the safety department of AAU CPH. The evacuation plan for navigating the hallway is inspired by the existing Escape Route to help navigate the player out of the hallway. Additionally, all available rooms and exits have a near 1:1 replica of the existing signs based on AAU CPH's campus.
Interaction behavior with others	The player will have opportunities to notify another student unaware of the alarm and will require the player's help to evacuate. This is only possible should the player take it upon themselves to check for other students, otherwise the player will engage in dialogue with a firefighter, and be questioned as if the player has the role of an evacuation leader.
Interaction behavior with environment	During the task, an attachment is set towards finishing a pending task so you can get a document, this is to challenge the player's temptation to wait for the document to finish despite being instructed to evacuate as a matter of risk-taking decision-making.

Table 5: Behavioral theories applying to the game, and how they were implemented

The game simulates an evacuation drill. Players go sequentially through several tasks, which are automatically updated during gameplay, visualized in figure 2. Blue squares indicate tasks that do not involve any choices. Green squares indicate a correct choice and red squares indicate incorrect choices. The purple squares are optional and mutually exclusive choices, as the player can either evacuate the student or inform about the student should the player choose to do so, but not both.

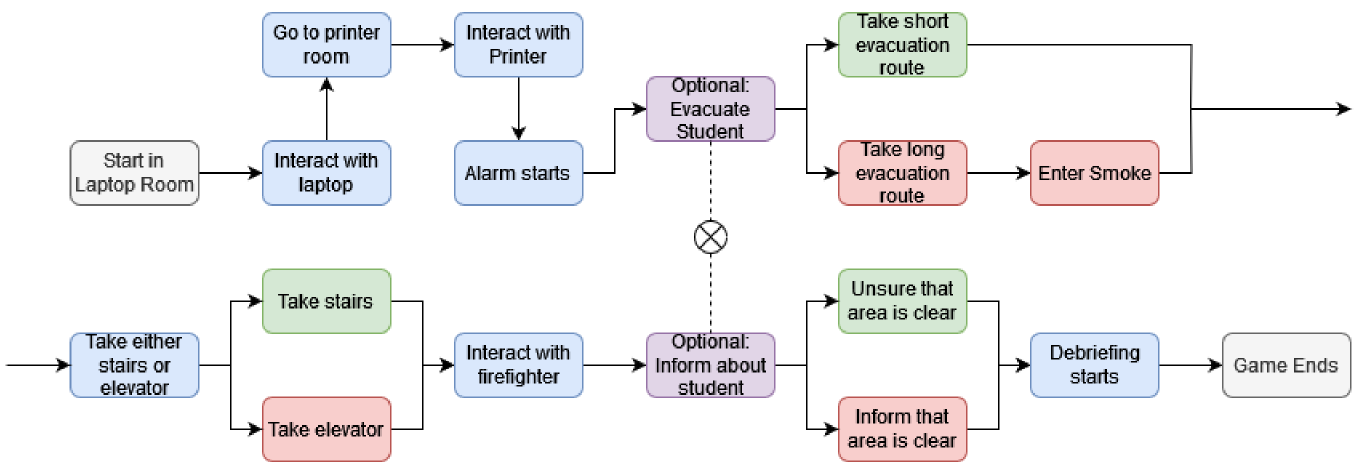

Figure 2: Flowchart of the game showing the sequential tasks and choices a player can make during a playthrough.

Note that there are three evacuation plans distributed in the level, which players can look at to get an understanding of the layout of the level. The evacuation plans are not represented in figure 2, as this is an optional choice the player can engage in at any point before they evacuate. These tasks are visible to the player in the top left corner of the screen, to guide the player. Certain areas are blocked via locked doors until the player has completed the corresponding task. This limits the play area and prevents sequence breaking such as evacuating the building before the alarm sounds. The level is based on the BIM that uses information from AAU-CPH and includes two possible exits at either end of the hallway, both containing stairs and an elevator. At the end of the stairs and elevators, the player will encounter a firefighter NPC. Doors automatically close 5 seconds after they are opened. This prevents the player from going back into the building after evacuating by relocking the doors located just before the stairs and elevator.

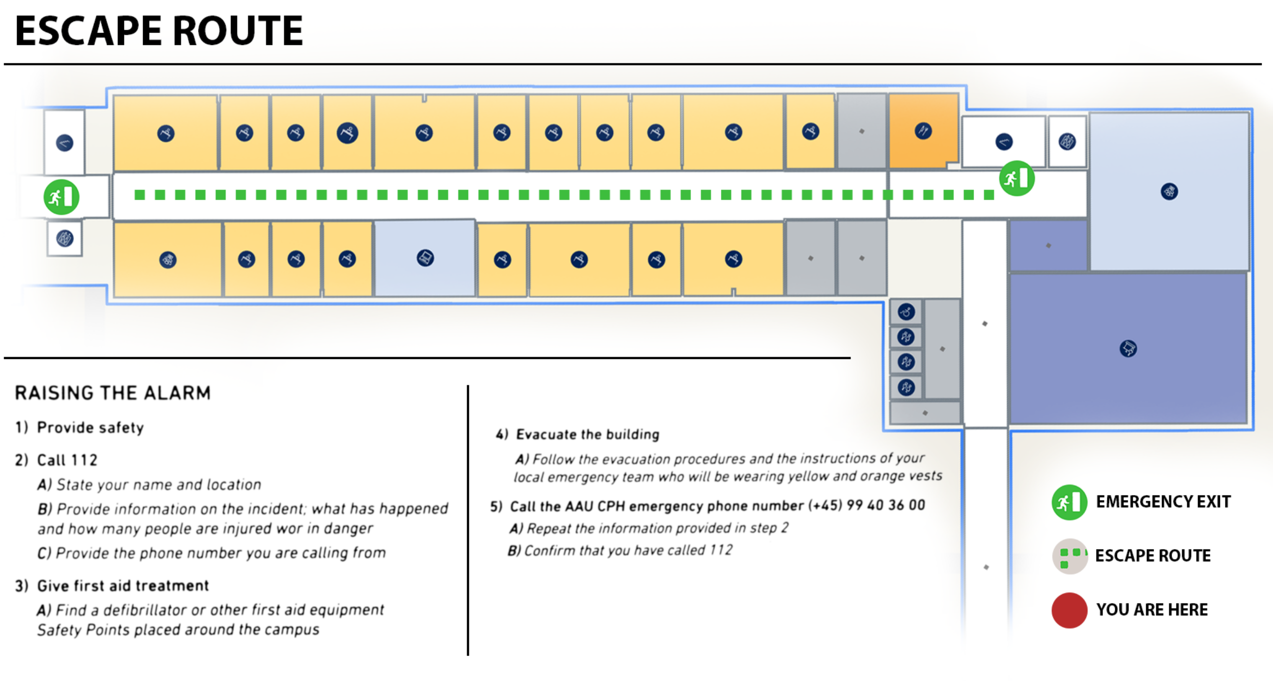

Figure 3: Escape plan containing a map of the level and evacuation instructions.

Task 1: Use Laptop To Print Documents. The player starts in a classroom. There is a laptop on a table that the player can interact with to complete this task. The room's door is locked during this task to prevent players from leaving before players have interacted with the laptop. This is done to make the player aware of the objective-based nature of the game and allow the player to get used to the controls in a smaller environment. This also prevents frustration or confusion of needing to backtrack back to the laptop if the door had been unlocked from the start and the player leaves the room without interacting with it. To further alleviate frustration, important objects are framed within the golden ratio every time the player leaves or enters a room, so the player's eyes rest on them.

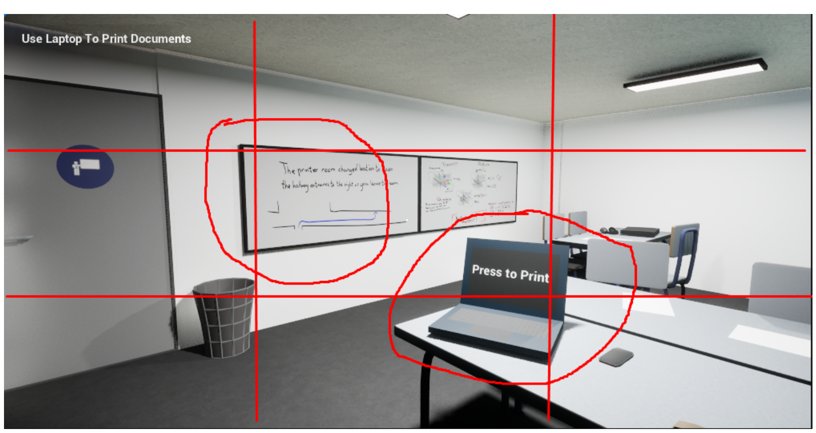

Figure 4: The player is presented with important information to fit the golden ratio when starting the game.

Task 2: Go to the Printer Room. Once the laptop has been interacted with the player can enter the hallway. As the task doesn't inform the player of the printer room's location, it is expected that the player will use the evacuation plans on the walls to get a better understanding of the layout or use the information conveyed on the whiteboard shown in figure 5. The printer room is also marked by an icon on the door and clutter by the floor. The doors to classrooms other than the printer room are non-functional to minimize time wasted by the players in entering empty classrooms and the doors leading to the emergency exits are locked to limit the play area and prevent sequence breaking. There is a blue student NPC wearing headphones located between the player's starting classroom and the printer room. The player will be able to hear music originating from the student and should the player choose to interact with the student, they will be informed that the student doesn't seem to be aware of them. This is to increase the believability that the student wouldn't necessarily hear the evacuation alarm and that the player might need to provide assistance at that stage.

Figure 5: In-game screenshot of the interior of printer room and door marked with printer sign.

Task 3: Print Documents. Upon entering the printer room, the player needs to interact with the printer, which players can immediately see upon opening the printer room door as seen in figure 5.

Task 4: Wait For Documents to Print. Upon interacting with the printer, the player has to wait. After 10 seconds have passed, the evacuation alarm will sound. 15 seconds into the alarm, the task will change to task 5. The reason for this delay is to avoid informing the player that they need to evacuate before they have heard the evacuation alarm instructions.

Task 5: Evacuate The Building OR Wait for Printing to Finish. Both the correct and incorrect choice is shown, letting the player decide which to follow. The correct choice is kept intentionally vague, evacuate the building, rather than something more descriptive such as including directions. This puts the focus on the player's decision-making regarding evacuation and allows for further correct or incorrect choices during the evacuation without the need for prompts. Possible choices during the evacuation include; taking the longer or shorter route to the exits, evacuating the blue student, or checking the evacuation plans.

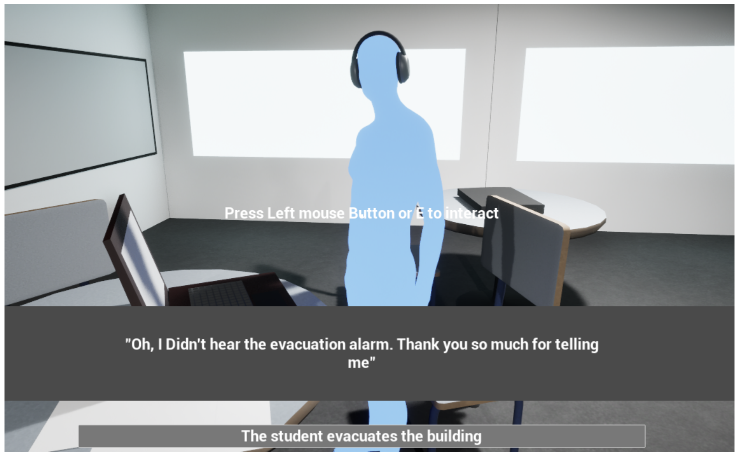

Figure 6: An instance where the player interacts with the student during the evacuation.

After the 15-second delay when the alarm starts, the player has 180 seconds to evacuate for the game to consider the evacuation "successful". The incorrect choice of waiting in the printer room only results in the player wasting time, as the documents will never finish printing. It is not expected that the player will spend much if any time waiting for the documents, however, as there is little to no incentive to disobey the alarm. This is mainly a cognitive and motivational issue, that is difficult to simulate in a serious game. In a real-life scenario, it can be assumed that some potential reasons for delaying one's evacuation would be due to wanting to save personal objects. While the scenario presented in the game involves a small task given to the player using a laptop and printing documents, the player has no real attachment to the virtual laptop or documents to be printed, as these are simply part of the game and not something the player would feel any kind of ownership over. In a real-life scenario, the player would have more reasons to not evacuate immediately, as potentially losing what would be their own laptop, would cause the player to lose not only in the monetary aspects but also whatever the contents of their laptop would be. Therefore the player would likely be more inclined to stay in the building to collect any owned objects despite the correct procedure being to evacuate immediately, which is not the case in the game.

Figure 7: In-game screenshot of the hallways leading to the closest emergency exit to the printer room

Task 6: Take The Elevator OR Take the Stairs. Upon reaching either of the exits, the player will enter an invisible collider. The player is then given a choice between using either the stairs or the elevator to evacuate. Either option will result in the player evacuating and progressing to the next task. Compared to other evacuation games described in section 2.4 where taking the elevator results in failure and restart of the scenario, an early game over in this game would result in less information given to the player. In this scenario, an early game over, should the player take the elevator, would have resulted in the player not speaking to the firefighter NPC. By not speaking to the firefighter NPC, the player would not have gained any information from that encounter. It would not have been ideal to have the players replay the level after an early game over. The data logging would be negatively affected, due to the complexity with data logging potential "failed" playthroughs. A player could also be affected by knowledge gained from previous playthroughs, such as a faster evacuation time compared to a player who successfully evacuated during the first playthrough.

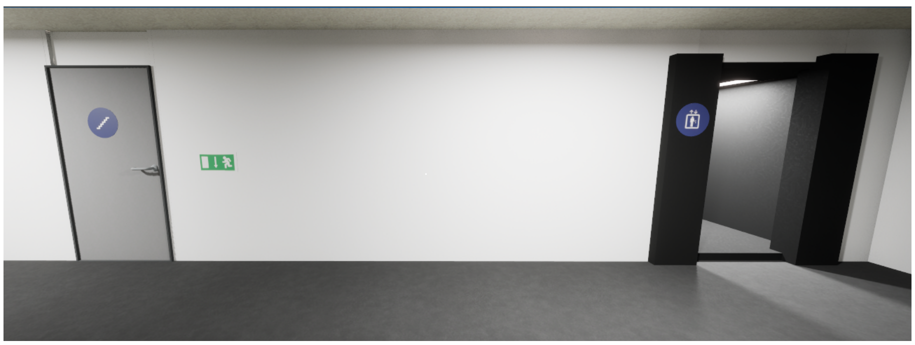

Figure 8: An instance where the player is presented with two possible directions.

Task 7: Talk to the firefighter at the meeting point. Upon successfully evacuating via either the stairs or the elevator, the player is prompted to speak with a red firefighter NPC. The firefighter will force the player to assume the role of an evacuation leader and question the player based on an evacuation leader's responsibilities. This was done as both a surprise factor to the player and to convey information about what an evacuation leader and their responsibilities are. Forcing the player to assume the role of the evacuation leader was done as a light introduction to the role, as it was conveyed in the expert interview that it was rare for people to take the initiative to take the role of evacuation leader. The player is given the opportunity to inform the firefighter about the student if the player didn't help the student evacuate. Both informing the firefighter about the student or evacuating the student themselves is considered correct, with the incorrect choice being doing neither. The dialog options that inform the firefighter about the student is intentionally written to not remind the player about the student, being "No" when asked by the firefighter if anybody is still in the building, with "Yes" and "I'm not sure" being the alternatives. The option is presented this way, as a more descriptive option, such as "There is a student" or even a more vague "there was someone", could have reminded the player about the student during the dialog with the firefighter rather than because they actually remembered the student or made a decision not to help them during their evacuation.

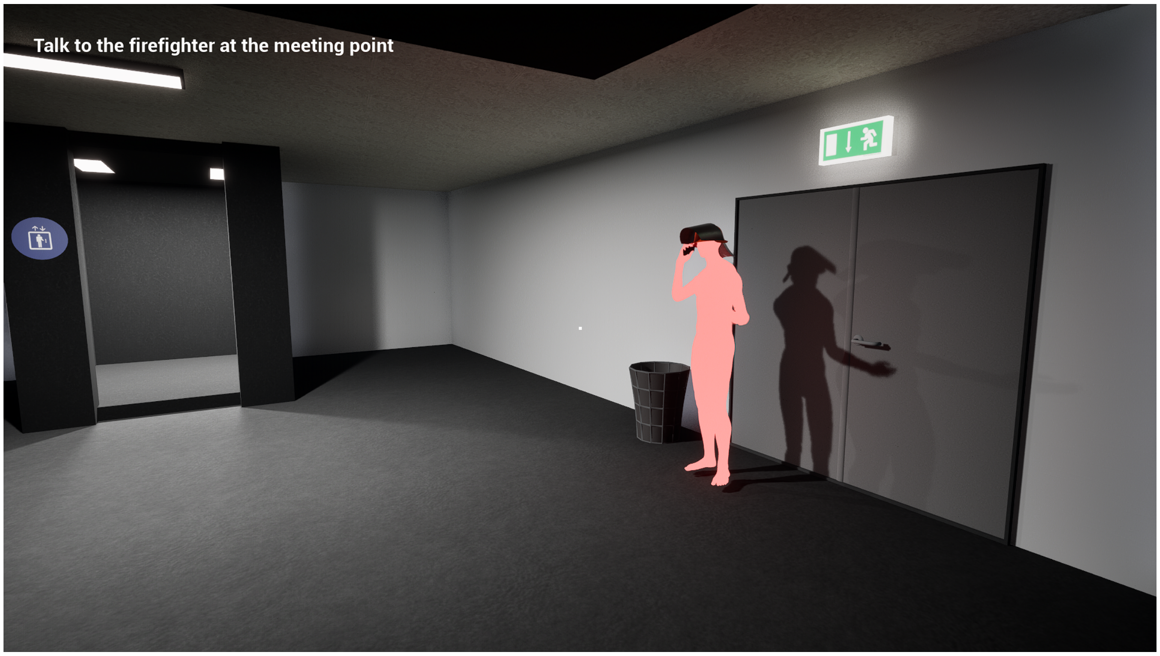

Figure 9: In-game screenshot of the firefighter the player needs to speak to after using either stairs or elevator.

Task 8: Get debriefed regarding your choices. A few seconds after the player speaks to the firefighter, a debriefing will automatically appear on the screen. The debriefing contains the choices the player could make during the evacuation and dialog with the firefighter. The choices include; Did the player evacuate successfully within the 180 seconds time limit, whether the player used the stairs or elevator, did the player evacuate the student, inform the firefighter about the student, or neither, did the player say the area was fully evacuated, and did the player take the short or long route to evacuate. All correct choices are explained to the player as to why they were the correct choices and incorrect choices are likewise explained as to why they are incorrect. Additionally for incorrect choices, the correct choice is presented as well and explained. For multiple correct choices, in the case of the student where both personally evacuating the student and informing the firefighter are correct, the alternative choice is also presented to the player and explained, with the debriefing making it clear to the player that both options are correct and mainly dependent on the situation. When the player is done with the debriefing, the game automatically returns to the starting menu where the game can be restarted.

4 Implementation

The data logging is created in a string array at the start of the game. The array is created by importing a CSV containing the column names, which mark the logged data and make up the initial row. An integer array the same size as the string array is created at the start of the level and populated with 0s. The 0s are placed underneath the initial column to mark all the logged data. When a player takes an action that would be datalogged, such as entering the elevator or evacuating the student, the event EditChoice is called. As seen in figure 10 EditChoice replaces the 0 with a 1 in a specified index, in order to mark that the player has taken that action in their playthrough. Edit Time Looked is used for objects that log how long time a player has looked at the object, with the additional input of time. Time is how many integer seconds the player has looked at the object and replaces the initial 0 in the specified index.

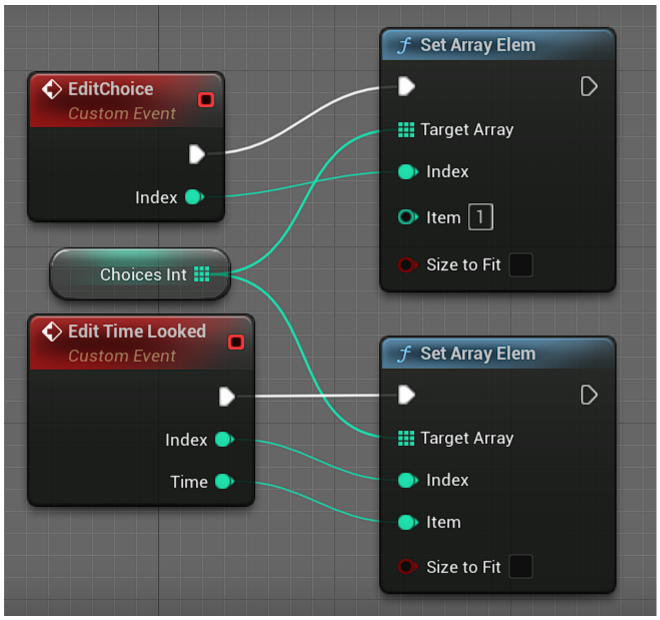

Figure 10: The two custom events EditChoice and Edit Time Looked, both set a certain element of an integer array to either 1 or a custom number.

When the debriefing begins, the integer array is first converted to a string array as seen in figure 11 by looping through the entire array and adding each element to a new string array. This string array is then converted into a comma-separated string. This string is then converted back into a string array and appended to the initial string array as seen in figure 12.

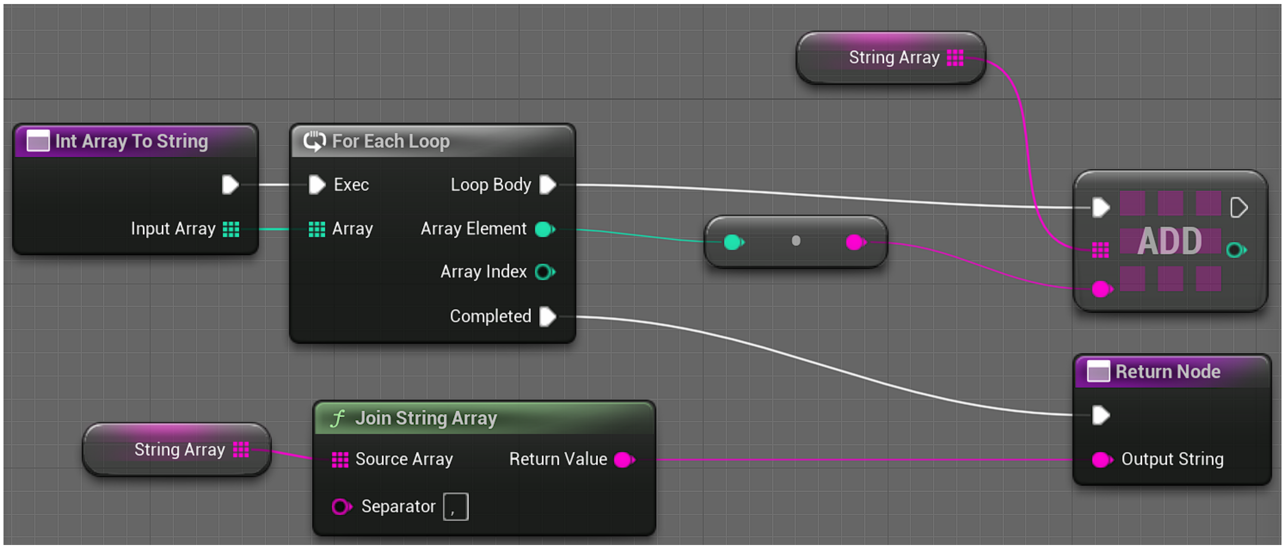

Figure 11: The Int Array To String blueprint component, when called, will convert the integer array input into a comma-separated string

Converting from the array to a comma-separated string and back to an array again is done to convert the initial data from being logged as a column in the CSV file to instead be logged as a row. Once the debriefing ends, the player is returned to a starting menu and their playthrough is over. The scenario can be restarted, allowing the data to be contained in a single CSV file as long the application is not shut down. Each row within the CSV file will represent a single playthrough of the game, with each additional row representing a new participant.

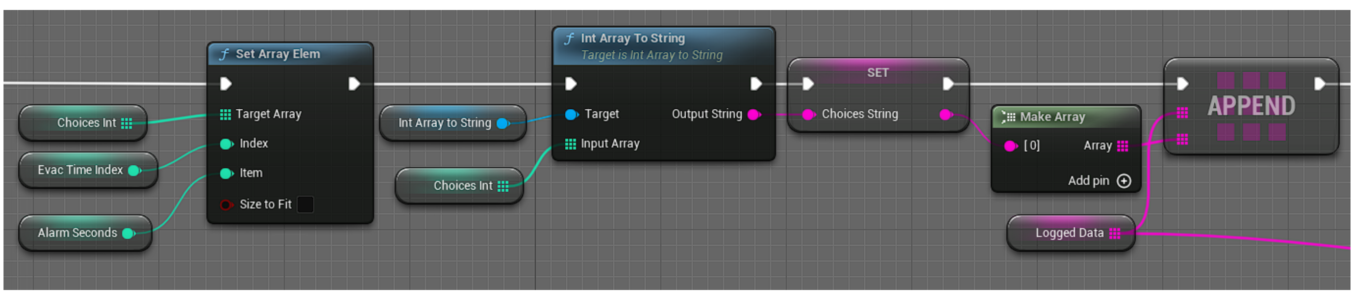

Figure 12: Blueprint excerpt containing parts of the logic that creates the data row upon completion of the game.

The tasks being updated are handled similarly. At the start of the game, a data table containing the object descriptions is imported and each element in the data table is added to a string array as seen in figure 13. The original CSV file containing the data is called ObjectiveStrings and the row imported is Level1. The contents of the row are then broken into each string array index before being set as the initial objective string.

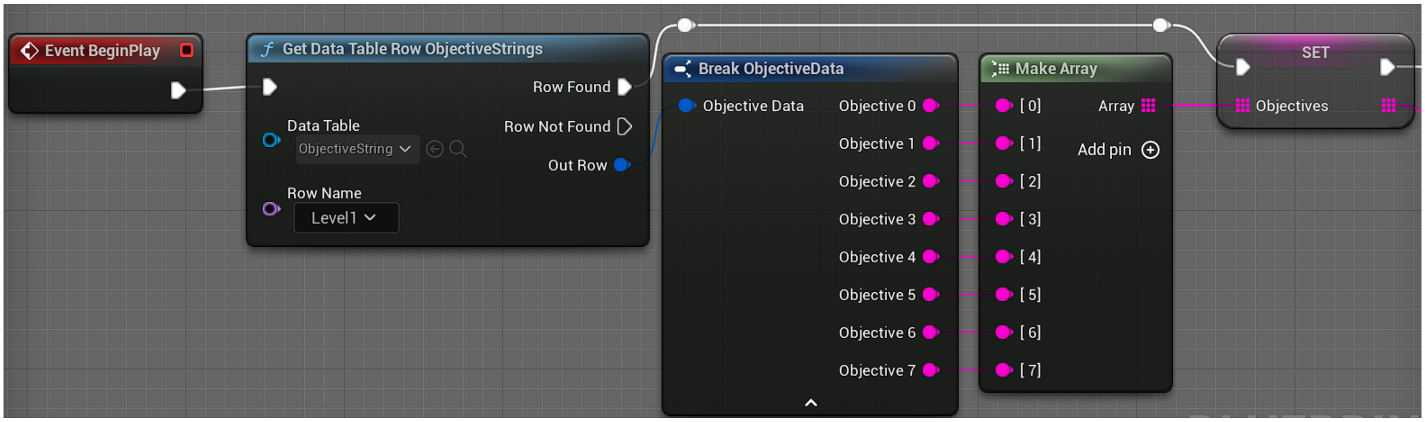

Figure 13: Blueprint excerpt showing the data table being imported and each data table element being broken and added to an array.

These elements in the data table can be accessed by using a Get function, where the string for the current element is added to the player's viewport, thus showing the current task to the player. By using the get function in combination with an input int, the task can be updated during gameplay as the player completes them.

5 Method

A pre-post experiment is employed to measure participants' engagement levels and verify knowledge assessment by offering a serious game to play in a prepared setup. The pre-post experiment was split into five parts: 1. Concept test and pilot testing; 2. Knowledge assessment; 3. A questionnaire with UES-sf-inspired questions; 4. Data collected from the game; 5. Observations.

1: A concept test was conducted to gain insight into players' understanding of the questions they would be asked in a setting with no game or prototype. It was found that the questions needed to be clear and direct with as few questions and answers as possible. The UES-sf shows that some questions were too close semantically and had to be removed or changed to be positive. Therefore the UES-sf is not directly used but inspired. Two pilot tests were conducted to ensure that the learning goals, game design, implementation & procedure were functional. Acquired participants for the first pilot test, were through convenience sampling on AAU-CPH Campus. It was discovered that the game was too implicit and thus iterated on making the goals more explicit. The second test used the same method of gathering participants and found redundancies in some of the datalogging in the game since players did not stop to read pages of information, players also struggled to read the maps from AAU-CPH and engagement was very low.

5.1 Participants

The study involved students from various study programs at AAU-CPH. Participants were found by convenience sampling, sampling students from various programs. The test was conducted by setting up a "stall" with our test in a corridor between two buildings.

Leading participants to the testing area was used as an opportunity to build rapport, like their study program to keep track of, and avoid too many students from the same study. It was also a source for gaining noteworthy knowledge written in a collection of observation notes. This also increased the likelihood of the participants cooperating when asked to help with snowball sampling.

By participating, students were rewarded with the option to pick a bar of chocolate that had a value of nine to 15 DKK depending on the type. Distributing rewards allowed both convenience sampling, and the likelihood of snowball sampling when participants realized they got rewarded for participating. One participant chose not to take a reward. Participants were informed about the reward if they asked when approached. The rewards were on full display at the stall, for passersby to notice. All participants gave informed consent and they could withdraw at any point during testing. They were also anonymized with ID numbers. Participants were also informed that any level of reading comprehension and gaming ability was acceptable for the test and that they could proceed at any speed or ability without being hurried or judged. In total, 57 students participated; 41 male, 12 female, and 3 nonbinary with one choosing not to say. Some students disclaimed that they were also staff but primarily students. 39 people had been at AAU-CPH for 1-3 years, with 18 being there for 4-5 years. 37 participants were 18-25 years old, 19 were 26-35 years and one was 36-45 years old.

5.2 Procedure

The experiment uses data collected through four questionnaires: The participant information questions, one pre-test and post-test knowledge assessment questionnaire, and the UES-sf inspired questionnaire.

The stall was rigged with two laptops, one with the game and one with the questionnaires, with the ability for the participant to either sit or stand at any point. Participants started with the first part of the questionnaire and then switched laptops until the game was finished then returned to the first laptop to answer the remaining questions. Participants were briefed on the procedure and their rights according to GDPR with informed consent before starting the test. The participants were asked to answer general questions regarding their age, role at AAU-CPH, and how long they had been at AAU-CPH. Four questions regarding their knowledge of fire evacuation related to the procedure on AAU-CPH were also asked. Participants were then asked to play the game to completion where they subsequently were asked to answer a questionnaire with the same four questions relating to their knowledge of fire evacuation. The knowledge assessment questions were based on the success criteria. Items from the UES-sf were included to measure participants' engagement (O'Brien, Cairns, & Hall, 2018), these questions were measured on a 5-point Likert scale.

2: The knowledge assessment consisted of the same questionnaire that the participants had to answer before they played the game and after playing the game. The knowledge assessment questions had four questions with three possible answers. Only one of the answers is correct. The questions and answers are in table 6.

Q1: When I have heard the alarm, I should do the following?	**Q2: While evacuating I should, as the main priority?**	**Q3: If I don't know where the nearest emergency exit is located, I would be able to find out by?**	**Q4: In case of an evacuation, do you know which color vest an evacuation leader is wearing?**
Q1.1: I find the nearest map of emergency exits in my area.	Q2.1: Focus on getting out as quickly as possible.	**Q3.1: Looking at the emergency plan for my area in the building.**	Q4.1: They are wearing the orange vest.
Q1.2: I close the windows and doors when I hear the alarm.	**Q2.2: Avoid using elevators when evacuating.**	Q3.2: Asking someone else where the emergency exits are.	**Q4.2: They are wearing the yellow vest.**
Q1.3: I finish my work, then evacuate with my stuff.	Q2.3: Ensure all doors and windows are closed before I leave the area.	Q3.3: The evacuation alarm will inform me where the exits are.	*Q4.3: They are wearing the red vest.*

Table 6: Knowledge assessment questions, asked before and after the game. Correct answers are marked in bold.

3: After playing the game, participants were asked to answer the modified UES-sf. The UES-sf inspired questionnaire had some modifications where the questions were changed to all be positive. This meant the requirement to revert the subscale of perceived usability (PU1, PU2, PU3) was eliminated. One question from the aesthetic appeal was dropped since the pre-test showed that participants did not feel there was enough of a difference between the two other questions in aesthetic appeal.

ID	**Focused Attention**
FA1	I lost myself in this experience
FA2	The time I spent playing the game just slipped away
FA3	I was absorbed in this experience
	Percieved Usability
PU1	While playing the game I felt encouraged
PU2	I found the game simple to use
PU3	Playing the game felt easy to me
	Aesthetic Appeal
AE1	The game was attractive
AE2	The game was aesthetically appealing
	Reward
RW1	Playing the game was worthwhile
RW2	My experience was rewarding
RW3	I felt interested in this experience

Table 7: UES-sf inspired questions that were asked after participants had played the game. Items were shown on a 5-point Likert scale.

4: Data collected through the game logged which escape plans players looked at, how long they looked at each escape plan, Participants' choice of whether to evacuate using the elevator or stairs, how long it took them to evacuate after the emergency announcement, and finally their choices, based on the surprise mechanic. These data entries were logged in a CSV file to be read by a Python script that would return the data in datasets to be made into figures and tables that would summarise our participants' choices. The datasets were split into five different sets. The evacuation choices, the surprise mechanic choices, the time looked at escape plans, and the evacuation time.

5: While testing, one researcher would stand by to answer questions from the participants. As the participants were playing the game, the researcher would take notes from their observation of how the participants were performing. This could be if the players saw the clues of where to go, looked at the escape plan, or if they just walked around randomly to try and open doors. The notes were written into a sheet where segments had been prepared before testing so it was possible to mark if the participants were from buildings A, B, or C if they had played games before, or if they asked questions about any of the questionnaires.

5.3 Data Analysis

The collected data were analyzed using a data partitioning Python script with relevant libraries to transform the data from raw CSV datasets to usable figures. Data was collected from SurveyXact where it was split into the four needed datasets before being read by the Python script. These four datasets were participant data, knowledge assessment questions before, knowledge assessment questions after, and UES-sf data. The data logged in the game was also read by the Python script.

Due to the data having a non-parametric distribution, it is not possible to perform a Dependent T-test on the knowledge assessment questionnaires while ensuring that the data has validity. The non-parametric distribution is further supported by a Shapiro-Wilk test performed on the UES-sf data. To ensure that the UES-sf data has validity the Cronbach's alpha method is used on all the subscales and their items. Likewise, an overall score is also calculated. A score was calculated for each subscale to be able to specify if any, concerns that may contribute to a lesser degree of validity. The knowledge assessment questions were treated using the Wilcoxon Signed-Rank Test. The knowledge questions were evaluated by comparing before playing the game with the data collected after playing the game.

6 Results

6.1 Game logging data

Evacuation choices: Regarding the route participants chose to use for evacuation, 57 people chose to evacuate using the stairs, and 0 people chose to use the elevator. 10 participants entered the smoke in the hallway. Since no player took the elevator they didn't get the information from the debriefing regarding taking elevators during a fire evacuation. Due to the design of the game, it is not possible to determine if entering the smoke is equal to taking the long route, as the player could have turned back and taken the short route after entering the smoke. This would, however, technically be the longest route a player could take for an evacuation.

Entered smoke	Took stairs	Took elevator
10	57	0

Table 8: Evacuation choices and if participants entered smoke. Each participant only contributes one value to the score. n = 57.

Surprise mechanic choice: Seven participants chose to evacuate the student whereas 12 participants chose to inform about the student. four participants said the area was clear. One participant chose to inform that the areas were clear even when they did not evacuate the student nor informed about the student's possibility of being in the afflicted area.

Evacuated student	Informed about student	Told area was clear
7	13	4

Table 9: Choices of surprise mechanics in the game. n = 57.

Time looked at the Escape Plans Participants had a mean time of 5.25 seconds for the first escape plan, 2.67 seconds for the second escape plan, and 0.39 seconds for the third escape plan. The third plan was the least viewed due to its position being near the end of the long route. If a participant did not look at the escape plans, they contributed a 0 to the score for each escape plan.

	Mean (s)	**SD (s)**	**Min (s)**	**Max (s)**	**Partipants observed escape plans**	**Partipants not observed escape plans**
Escape Plan 1	5.25	8.72	0	42	34	23
Escape Plan 2	2.67	4.09	0	20	29	28
Escape Plan 3	0.39	2.30	0	17	3	54

Table 10: Time in seconds all participants observed the escape plans in the game. n = 57.

While table 10 gives an overall impression of how participants performed, it includes all the "0" sum values.

In table 11 participants who actively looked at the escape plans and contributed with a score higher than 0 are used. In other words, participants who, actively looked at the escape plans. Values with a score of 1 or higher are included to give an alternative view of the time spent observing the escape plans. The participants who did not observe the escape plans are not included in table 11.

The total time spent observing each escape plan was added to provide an overview of which escape plans were observed the longest.

	Median	**Mean**	**SD**	**Participants observed escape plans**	**Participants not observed escape plans**	**Total time observed escape plans**
Escape Plan 1	5.5	8.79	9.84	34	23	299
Escape Plan 2	4	5.24	4.40	29	28	152
Escape Plan 3	4	7.33	8.50	3	54	22

Table 11: Corrected value of only participants' time who observed the escape plans.

Comparing the data, regarding table 10 and table 11 there is a difference in both the mean values and SD. Table 10 does not show how long individual participants looked at the escape plans. To show this the data were loaded into a histogram. This histogram shows the three escape plans for each participant. It should be noted that since escape plans are logged throughout the game, a long duration spent observing escape plans does not necessarily mean a longer evacuation time, as participants could have observed escape plans before the alarm.

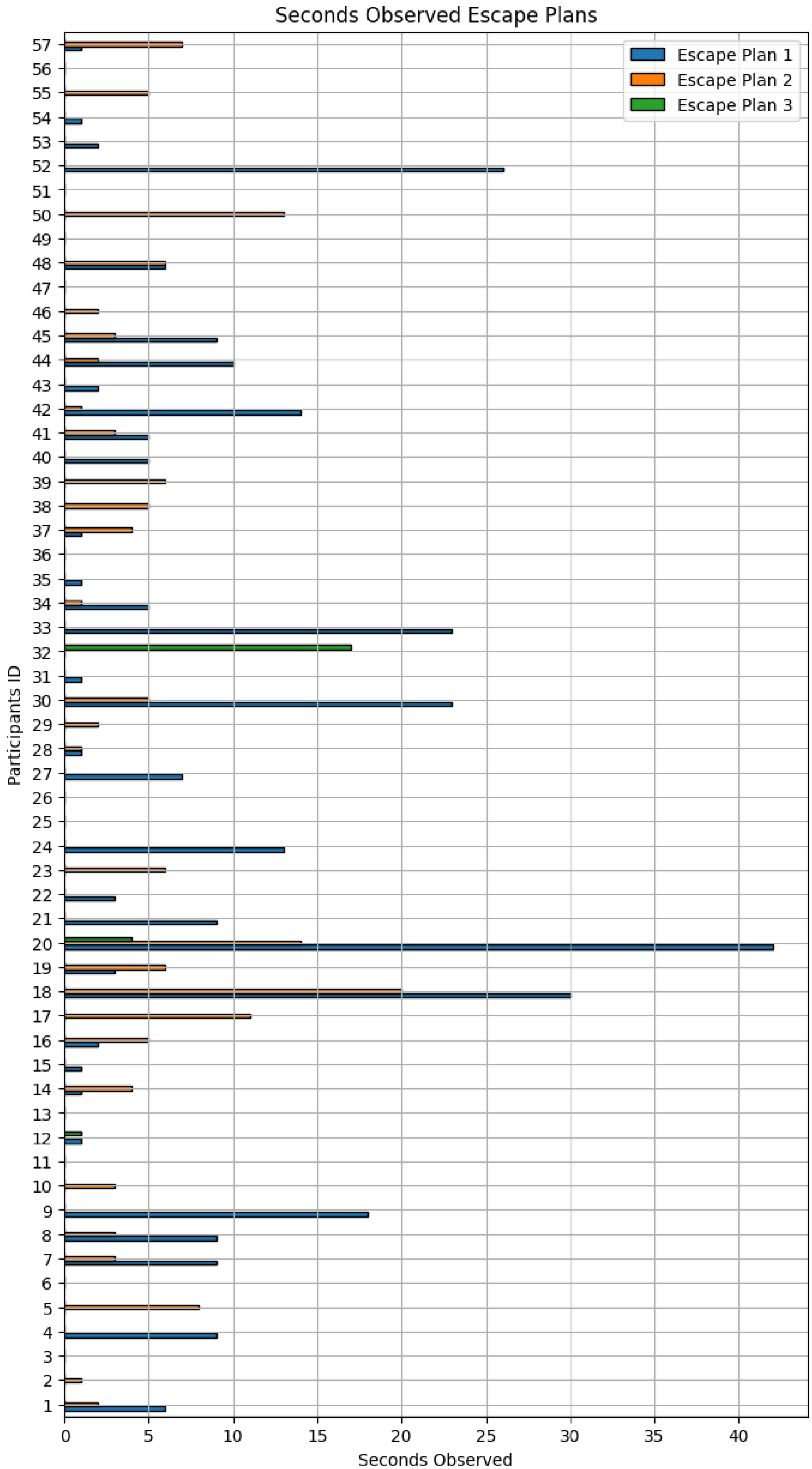

Figure 14: Histogram of the duration each participant observed the escape plans. Y-axis shows the individual participants. X-axis shows the number of seconds. n = 57.

Evacuation Time: Expected evacuation times were between 30 and 60 seconds for participants who understood Danish, due to the alarm instructions being conveyed in Danish 15 seconds after the alarm was sounded. An additional 15 seconds were expected to be added for non-danish speaking participants, as alarm instructions would be conveyed in English 30 seconds after the alarm was sounded, for an expected evacuation time between 45 and 75 seconds. As can be seen in table 12, participants were on average able to evacuate faster than expected. On average, participants took 33.89 seconds to evacuate from when the alarm sounded to choosing an evacuation route. Participants had a standard deviation of 11.41 seconds for actual evacuation times between 22.48 and 45.3 seconds. The slowest evacuation time taken was 73 seconds and 21 seconds for the fastest. The values in difference, from table 12 indicate that participants were generally able to evacuate faster than expected.

	Expected evacuation time	**Actual evacuation time**	**Difference**
SD subtracted	30	22.48	7.52
Mean	45	33.89	11.11
SD added	60	45.3	14.7

Table 12: Expected and actual evacuation times in seconds. Difference was calculated by subtracting the actual evacuation time from the expected evacuation

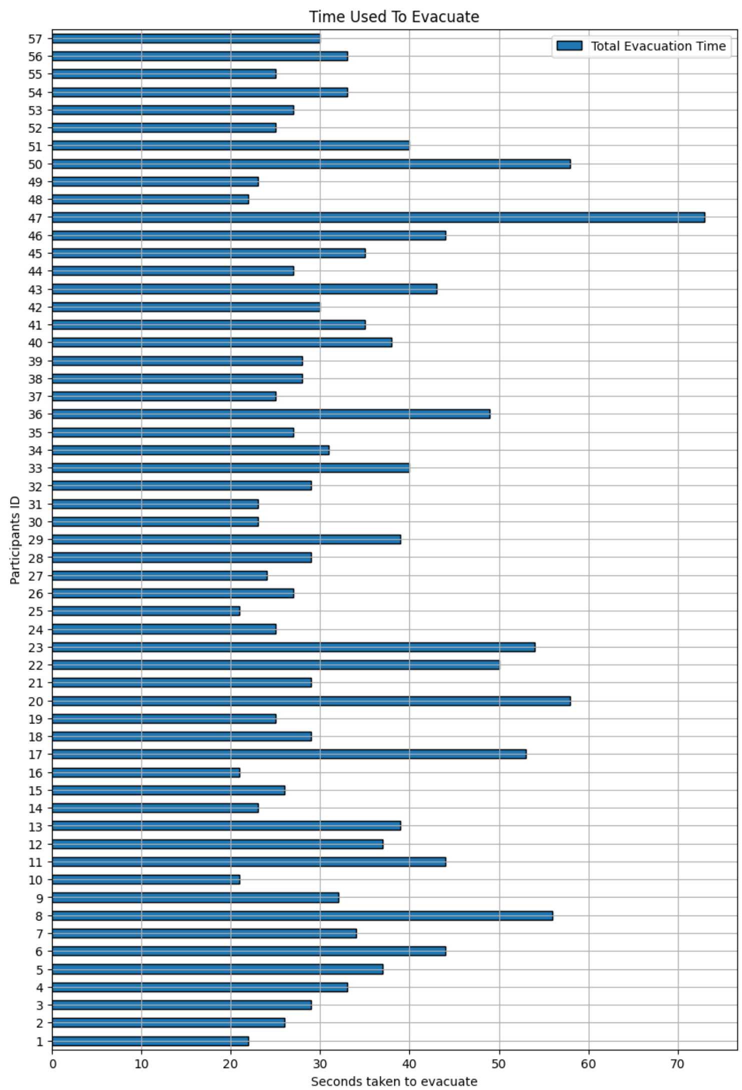

Figure 15: Histogram of participants' time to evacuate. Time is measured in integer numbers. n = 57.

6.2 Improved knowledge

Knowledge Questions: The knowledge test revealed that the participants had pre-existing knowledge about the more general procedures they should do in case of a fire as can be seen from their answers in Q.1, Q.2, and Q.3 before the game. The standard deviation does not change much from before versus after with the exception being the first question having a difference of -0.29 lower, Which could indicate that some participants changed their answers from the third option to the second or first which would give an overall lower standard deviation. Based on the data collected it can be said that the serious game managed to fulfill five out of six of the set success criteria with an increase in the percentage, that managed to answer correctly following playing the game. See table 15 for more information. An increase can be seen of 8.78% in Q.1, a 6.75% increase in Q.2, a 8.77% increase in Q.3, and a 22.80% increase in Q.4. Interestingly the game managed to make participants answer wrong in some cases, this was a bit unexpected since it did not correlate to what the participants were meant to learn. Although the overall number of answers increased in the correct numbers, some wrong answers increased. When it comes to fire evacuation there's a big gap in what one should be doing and what one is doing. The P-value of the knowledge assessment findings is generated by a Wilcoxon Signed-Rank Test, =< 0.05. The results from the knowledge test found no significant difference from before VS after with a P-value of 0.31.

	Before Game				**After Game**				
Questions	**% Corr**	**% Wrong**	**SD**	**Mean**	**% Corr**	**% Wrong**	**SD**	**Mean**	**Mean Diff**
Q.1: When I hear an alarm, I should do the following?	85.96	14.04	0.52	1.19	94.74	5.26	0.23	1.05	-0.14
Q.2: While evacuating I should, as the main priority?	31.58	68.42	0.56	1.39	38.60	61.40	0.60	1.49	0.10
Q.3: If I don't know where the nearest emergency exit is, I would be able to find out by?	77.19	22.81	0.47	1.25	85.96	14.04	0.51	1.19	-0.05
Q.4: In case of an evacuation, do you know which color vest an evacuation leader is wearing?	54.39	45.61	0.57	1.49	77.19	22.81	0.75	1.39	.0.11

Table 13: Knowledge questions before and after playing the game. n = 57.

6.3 High engagement

UES-sf: There were significant positively skewed results which meant that the data was not normally distributed. This led to treating the knowledge assessment question data with the alternative to a dependent T-test, namely the Wilcoxon Signed-Rank Test, which does not have as much power as its contemporary. The findings indicate that it was possible to create an engaging experience and that a game-based approach to teaching about fire evacuation can supplement existing knowledge with more direct and localized information. Across all subscales, in the UES-sf the average mean score was 3.57 for Focused attention, 4.32 for Perceived Usability, 3.76 for Aesthetic Appeal, and 4.21 for the Reward scores.

The 11 items are shown in a boxplot for an easy and fast overview of the min, max, and median scores and where the 50% quartile score range is. This further supports the notion that the data is not normally distributed since a true normal distribution can only be seen in question one (FA1). Outliers are present and can lead to some bias, however with the shape of the data being as it is, outliers do not take much to be created since the majority has answered very identically. This is especially visible in FA3 where the min, max, median, and 50% quartile are centered at a score of

4 on the Likert item. Shown with outliers marked as circles, circles in bold contain two or more outliers.

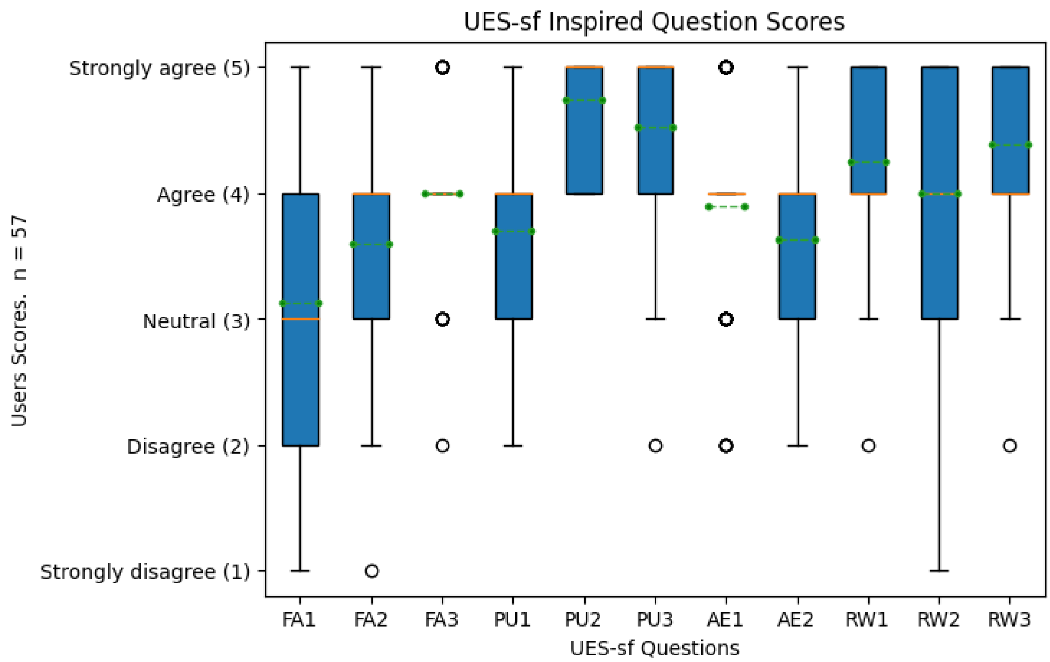

Figure 16: Boxplot of all scores of UES-sf inspired questions. Yellow line represents the median value. Green dashed line with green markers represents the mean value. n = 57.

	1	2	3	4	5	Total	Mean	SD	Cronbach's alpha (CA)	CA Total
Focused Attention						n = 57			0.72	0.75
FA1: I lost myself in this experience	3	14	17	19	4		3.12	1.04		
FA2: The time I spent playing the game just slipped away	1	3	17	33	3		3.60	0.75		
FA3: I was absorbed in this experience	0	1	5	44	7		4.00	0.53		
Percieved Usability						n = 57			0.74	
PU1: While playing the game I felt encouraged	0	5	14	31	7		3.70	0.80		
PU2: I found the game simple to use	0	0	0	15	42		4.74	0.44		
PU3: Playing the game felt easy to me	0	1	4	16	36		4.53	0.71		
Aesthetic Appeal						n = 57			0.73	
AE1: The game was attractive	0	4	10	31	12		3.89	0.82		
AE2:The game was aesthetically appealing	0	6	20	20	11		3.63	0.92		
Reward						n = 57			0.61	
RW1: Playing the game was worthwhile	0	1	4	32	20		4.25	0.66		
RW2: My experience was rewarding	1	0	14	25	17		4.00	0.85		
RW3: I felt interested in this experience	0	1	4	24	28		4.39	0.70		

Table 14: The UES-sf inspired questions, their mean score, standard deviation score, subscale Cronbach's alpha, and overall Cronbach's alpha score. n = 57.

Success criteria: Based on the results and their respective percentages it can be said that the study managed to accomplish five out of the six success criteria that were set out to be accomplished. Percentages shown in table 15 are the percentage of correct answers from the knowledge questions. The mean UES-sf score is calculated by taking the mean score of every answer from the individual participant and seeing how many participants achieved a score of 3.75 or higher out of the 57 participants.

Success criteria	**Score**	**Accomplished success criteria**
70% Are engaged with a combined mean score of above 3.75	Mean UES-sf: 70%	Yes
90% Know how to evacuate during a fire	Knowledge assessment: Q1: 94.74%	Yes
70% Know not to use an elevator during a fire	Knowledge assessment: Q2: 38.6%	No
70% Know always to try to take the shortest unblocked route to an emergency exit	Knowledge assessment: Q1 and Q3: 94.74% and 85.96%	Yes
90% Recognize the alarm warning about a fire evacuation	Knowledge assessment: Q1: 94.74%	Yes
70% Know the color of the evacuation leader's vest when an evacuation is active	Knowledge assessment: Q4: 77.19%	Yes

Table 15: Success criteria goals and the associated scores from the knowledge assessment and UES-sf questions.

The significance of the results, shown in table 15, indicates more than one thing. The UES-sf inspired questions had a score of 70% that did answer above the requirement of 3.75. This signifies that it is possible to say that it was an engaging experience for the majority of the players. Regarding the knowledge assessment questions, one success criteria were not achieved. It is not possible to say that the game has taught that players do not know that an elevator should not be taken during a fire. Having achieved 38.6% correct answers, it is indicated that some challenges with Q.2 are present. Q.1, Q.3 and Q.4 did get an increase in correct answers that achieved above the set goals of the success criteria. Q.1 with 94.74%, Q.3 with 85.96%, and Q.4 with 77.19% answering correctly. This shows that the participants do know how to evacuate, that they are knowledgeable that the shortest route should be taken during an evacuation, and that the correct color of the evacuation leader's vest was conveyed.

7 Discussion

Looking at the engagement scale based on UES-sf, the data is positively skewed with most outliers being negative. When monitoring participants during the tests, a select few participants were unable to pick up hints and directions for their task, which led to frustration caused by a lack of perceived usability. Future versions could have a greater emphasis on user error recovery to prevent user experience frustrations and test the application further away from upcoming exams and accumulated deadlines. Such external pressure combined with the open design of the application could have contributed to the negative outliers. The data collected from the UES-sf questionnaire has two main challenges. The challenges of the data not being normally distributed and the outliers present in the data.

The application achieved three technical achievements: One is that the interior is created with BIM, the second is making a believable simulated environment and the third is that the application was generally seen as engaging. This gave clearance to investigate learning outcomes through the knowledge assessment questions which all increased in correct answers, with the smallest change being 4 new correct answers and the largest change being 13 new correct answers. In total, there are two underperforming questions: Q.2 “While evacuating I should, as the main priority”, and Q.4 “In case of an evacuation, do you know which color vest an evacuation leader is wearing?”. Q.2 and Q.4 are both unorthodox and according to the remarks of some participants, were aspects of evacuation that they had never considered. Q.4, has a lower total correct answer percentage, compared to Q.1 and Q.3, but has taught the most participants, of a new concept with the largest increase in correct answers. This is a large change compared to common knowledge such as the best-performing question Q.1 “When I have heard the alarm, I should do the following?”, with only 5 answers seeing a positive change. Q.3 “If I don’t know where the nearest emergency exit is located, I would be able to find out by?”, had 5 answers as a positive change, but like Q.1 was already deemed common knowledge among most of the participants before playing the game.

Like Q.1 and Q.3, Q.2 sees a similar change, as the serious game prepares them to learn about not taking the elevator. It should be said that since the level is created with BIM, the level already follows safety practices, making it unlikely for the participant to use the elevator, which caused all the participants to exclusively take the stairs. It was expected that some people would take the elevator to get the unique debriefing dialogue advising against using the elevator. There is also the possibility that the question of Q.2 is semantically confusing, and it feels correct to choose Q.2.1 “Focus on getting out as quickly as possible.”. In a vacuum, this answer is correct, but that is if you do not take risk-taking into account for the time spent evacuating. Q.2.1 may have been clearer if it was put into the perspective of taking the elevator regardless. The debriefing could also have mentioned that the elevator would be ill-advised regardless of whether the player had taken the elevator or not. That might have made the knowledge question Q.2 easier to answer by the serious game being less implicit.

While the game successfully implemented BIM and a believable environment, questions such as FA3 "I was absorbed in this experience", challenge the implementation of an explorative hallway in a campus, where people either clock in or are on a deadline. This kind of game design may further contribute to frustrating gameplay. Future applications should practice some fire evacuation practices in a vacuum before accurately simulating the interior of a building to see how the participant may interact with the world. AE2 "The game was aesthetically appealing" was consistently reported to be semantically confusing and seemed identical to AE1 "The game was attractive". Participants were also more likely to feel indifferent about some aspects of the game because they were unsure what the question meant. Participants were only guided when they explicitly requested help with questions.

While the overall total percentage of correct answers for Q.2 is lacking, the positive learning result trajectory is promising for playing a serious game. Serious games are not a direct replacement, but an addition to training students regarding what to do during an evacuation, and should be paired with different media such as written instructions, infographics, animations, quizzes, and physical drills.

The Cronbach's alpha score from the subscales of the UES-sf is somewhat useable. Collectively the data has a score of 0.75 which is useable. The data in their respective subscales shows what part of the dataset has a lower validity, this indicates that more participants would probably be needed to correct our dataset. To judge if that was the case the data needs to be normally distributed since that is a pre-requisite for calculating Cronbach's alpha.

All participants were students and likely does not have the same training as the staff, it may explain why the total percentage of Q.2 was as low as it was. As opposed to if the population sample had been more balanced with students and staff.

In chapter 3, it was mentioned that there was a 15-second delay before the objective would change, and locked doors would unlock once the alarm started. The reasoning behind this delay was to avoid the objective pushing the player to evacuate before they listened to the alarm first. Observations during testing revealed that players would evacuate as soon as the alarm started, reaching the locked doors by the short emergency route before the 15 seconds had passed and would be unable to open the doors. Instead of waiting the remaining seconds, some players might have evacuated via the longer route, which would have resulted in a higher number of players being recorded entering the smoke and a higher total average for evacuation time.

Future versions of the game should reduce or remove the 15-second delay. This raises a question regarding a potential problem with the standard alarms or at least the perception of these alarms. The evacuation and the "barricade yourself inside the building" alarms use the same initial 15-second alarm sound before the verbal instructions start. This could cause problems if someone's initial reaction to hearing the alarm is to evacuate and the alarm turns out to be a "barricade yourself inside the building" alarm. Note there are differences between how someone would act upon hearing the alarm in a real-life scenario and how they would act in our game. In a real-life scenario, there would likely be some delay before an evacuation, such as the unexpectedness of the alarm. Due to the nature of the test, the players were aware that the game was about evacuation and were likely to assume that any alarm would be an evacuation alarm.

The results show that most players did not inform about or evacuate the student. While this could indicate that during an evacuation scenario, most people would mainly consider their evacuation over assisting others, it might instead have been due to not considering this a possibility in the game. Previous experiences with making serious games have indicated that various game mechanics and possibilities for the players often need to be explicitly told to the players, otherwise the players will not consider them. In the case of the student, players might not have assumed they could interact with the student at all.

In the current game version, the student can be encountered between the starting room and the printer room. The player has the option to interact with them or walk past them without any interventions. It might have helped if the student instead was blocking the path to the printer room or the seminar room, forcing the player to interact with the student to move them and make the player aware of the possibility of interacting with them.

Alternatively, additional distinct NPCs could have been added to the level and the player made aware of them while going to the printer room. Once the alarm started, these extra NPCs could have been moved to the room with the firefighter to indicate that these NPCs had evacuated on their own. Once the player successfully evacuates and interacts with the firefighter, they might notice that the student is not among the other NPCs.

8 Conclusion

The serious game is sufficiently engaging, achieving 70% of participants having a mean UES-sf score equal to or above 3.75, but contains outliers and is positively skewed. According to the knowledge assessment after playing the serious game, the success criteria "Know not to use an elevator during a fire” was not met by 38.6% answering correctly from the expected 70%. "Know how to evacuate during a fire" and "Recognize the alarm warning about a fire evacuation" both achieved 94.74% correct answers from the expected 90%. Finally, "Know the color of the evacuation leader’s vest when an evacuation is active" achieved 77.19% correct answers from the expected 70%, and "Know always to try to take the shortest unblocked route to an emergency exit" achieved 94.74% and 85.96% correct answers from the expected 70%.

The learning outcomes from playing the game are also consistently positive with the least positive change in the number of correct answers being 4 and the most positive change being 13 correct answers after playing the serious game. This further validates the use that serious games may connect with some users and educate them where other methods do not and have serious games supplement with existing training methods such as evacuation drills and courses.

Besides 1 success criterion out of 6 not being met, the research question **"Can a serious game be engaging and used to improve the knowledge about fire evacuation procedures at a university campus?"** is generally a success. Note that Q.2, is a question that needs to be re-evaluated, particularly how it is phrased in the questionnaire for the knowledge test in future research. While the other 4 knowledge questions and combined mean UES-sf score has exceeded the minimum expectations, they should still be re-evaluated to validate the results.

The game successfully implemented a believable simulated environment created with BIM, however this may have resulted in an overly easy evacuation scenario. While the accessibility of the game was likely improved due to the way the level was built, the simple layout, the visible signs marking evacuation routes, and evacuation plans, the game might have been too easy due to this, and knowledge gains were reduced due to players not being challenged enough and forced to draw upon that knowledge.

The simple layout could explain the overall low average means of 9.79, 5.24, and 7.33 seconds the escape plans were looked at, and the high number of players who didn’t observe the escape plans at all. A more complex layout of the level, which could potentially include dead ends, would have brought more attention to the usefulness of the escape plans. The elevators were also not used, as the elevators always had an accompanying staircase that could be used as an alternative evacuation route, with little reason to consider the elevator. Blocked staircases or hallways only containing elevators would have forced more consideration and thought from players. It would also have further emphasized the values of the escape plans as evacuation routes that only lead to elevators and not stairs would need to be avoided. Alternate scenarios, which included additional NPCs that required evacuation within a certain amount of would have brought more emphasis on the evacuation leader role.

Further research may also look into practicing different fire evacuation procedures in small tutorial-like instances in a vacuum rather than making one big simulation and relying entirely on player behavior to teach these practices. It would also be interesting to see if isolating it in those instances would impact player engagement, or if making a big simulation is worth the trade-off of being less clear with its learning outcomes for some players. Future research should also consider testing the application at the start or the middle of the semester, to avoid time-pressured participants.

9 References

AAU. (2019, February). *Aau generel beredskabsplan.* Retrieved from https://www.arbejdsmiljoe.aau.dk/digitalAssets/1310/1310277_aau-generel-beredskabsplan-2016-ver-1-4-feb-2019.pdf

AAU-Copenhagen. (2023, October). *Lokal beredskabsplan aau cph.* Retrieved from https://prod-aaudxp-cms-001-app.azurewebsites.net/media/1yxnmzsm/beredskabsplan_final_okt-2023.pdf

Alexander, K. P. (2013). The usability of print and online video instructions. *Technical communication quarterly*, *22*(3), 237-259.

Bjørner, T., Blume, N. B., Frederiksen, N. J., Hjort, V. S., Mørck, A. F., & Petersen, M. Ø. (2023). An engaging serious game that strengthens high school students' understanding of the periodic table. In *International conference on games and learning alliance* (pp. 3–12).

Bloch, S. A., & Bloch, A. J. (2013). Using video discharge instructions as an adjunct to standard written instructions improved caregivers' understanding of their child's emergency department visit, plan, and follow-up: A randomized controlled trial. *Pediatric emergency care*, *29*(6), 699-704.

Bourhim, E. M., & Cherkaoui, A. (2020). Exploring the potential of virtual reality in fire training research using a'wot hybrid method. In *Intelligent systems, technologies and applications: Proceedings of fifth ista 2019, india* (pp. 157–167).

Canter, D. (1980). Fires and human behaviour: Emerging issues. *Fire safety journal*, *3*(1), 41-46.

Carvalho, P. V. R. d., Ranauro, D. O., De Abreu Mol, A. C., Jatoba, A., & Legey de Siqueira, A. P. (2022). Using serious game in public schools for training fire evacuation procedures. *International journal of serious games*, *9*(3), 125-139.

Chen, S.-Y., & Chien, W.-C. (2022). Immersive virtual reality serious games with dl-assisted learning in high-rise fire evacuation on fire safety training and research. *Frontiers in psychology*, *13*, 786314-786314.

Chu, M. L., & Law, K. H. (2019). Incorporating individual behavior, knowledge, and roles in simulating evacuation. *Fire technology*, *55*(2), 437-464.

Daylamani-Zad, D., Spyridonis, F., & Al-Khafaaji, K. (2022). A framework and serious game for decision making in stressful situations; a fire evacuation scenario. *International journal of human-computer studies*, *162*, 102790-.

Feng, Z., González, V. A., Amor, R., Lovreglio, R., & Cabrera-Guerrero, G. (2018). Immersive virtual reality serious games for evacuation training and research: A systematic literature review. *Computers and education*, *127*, 252-266.

Hogg, M. A., & Reid, S. A. (2006). Social identity, self-categorization, and the communication of group norms. *Communication theory*, *16*(1), 7-30.

Hovedstadens-Beredskab. (2024). *Brand- og evakueringsinstrukser.* Retrieved from https://hbr.dk/brand-og-evakueringsinstrukser/

Janis, I. L. (n.d.).
Journal of social issues.

Kinsey, M. J., Gwynne, S. M. V., Kuligowski, E. D., & Kinateder, M. (2019). Cognitive biases within decision making during fire evacuations. *Fire technology*, *55*(2), 465-485.

Kobes, M., Helsloot, I., de Vries, B., & Post, J. (2010). Exit choice, (pre-)movement time and (pre-)evacuation behaviour in hotel fire evacuation — behavioural analysis and validation of the use of serious gaming in experimental research. In *Procedia engineering* (Vol. 3, p. 37-51). Elsevier Ltd.

Lin, J., Zhu, R., Li, N., & Becerik-Gerber, B. (2020). How occupants respond to building emergencies: A systematic review of behavioral characteristics and behavioral theories. *Safety science*, *122*, 104540-.

Menzemer, L. W., Ronchi, E., Karsten, M. M. V., Gwynne, S., & Frederiksen, J. (2023). A scoping review and bibliometric analysis of methods for fire evacuation training in buildings. *Fire Safety Journal*, *136*, 103742. Retrieved from https://www.sciencedirect.com/science/article/pii/S0379711223000103 doi: https://doi.org/10.1016/j.firesaf.2023.103742

O'Brien, H. L., Cairns, P., & Hall, M. (2018). A practical approach to measuring user engagement with the refined user engagement scale (ues) and new ues short form. *International journal of human-computer studies*, *112*, 28-39.

Proulx, G., & Reid, I. M. A. (2006). Occupant behavior and evacuation during the chicago cook county administration building fire. *Journal of fire protection engineering*, *16*(4), 283-309.

Quarantelli, E. L. (1954). The nature and conditions of panic. *The American journal of sociology*, *60*(3), 267-275.

Rüppel, U., & Schatz, K. (2011). Designing a bim-based serious game for fire safety evacuation simulations. *Advanced engineering informatics*, *25*(4), 600-611.

Sacfung, A., Sookhanaphibarn, K., & Choensawat, W. (2014). Serious game for fire safety evacuation plan. *Advanced Materials Research*, *931*, 583–587.

Schnellinger, M., Finkelstein, M., Thygeson, M. V., Velden, H. V., Karpas, A., & Madhok, M. (2010). Animated video vs pamphlet: Comparing the success of educating parents about proper antibiotic use. *Pediatrics (Evanston)*, *125*(5), 990-996.

Silva, J. F., Almeida, J. E., Rossetti, R. J. F., & Leca Coelho, A. (2013). Gamifying evacuation drills. In *2013 8th iberian conference on information systems and technologies (cisti)* (p. 1-6). AISTI.

Sweetser, P. (2021). Gameflow 2020: 15 years of a model of player enjoyment. In *Proceedings of the 32nd australian conference on human-computer interaction* (p. 705–711). New York, NY, USA: Association for Computing Machinery. Retrieved from `https://doi.org/10.1145/3441000.3441048` doi: 10.1145/3441000.3441048

Sweetser, P., & Wyeth, P. (2005). *Gameflow: a model for evaluating player enjoyment in games* (Vol. 3) (No. 3). New York: ACM.

Thompson, O. F., & Wales, D. (2015). A qualitative study of experiences, actions and motivations during accidental dwelling fires. *Fire and materials*, *39*(4), 453-465.

Wolf, M., & Teizer, J. (2022). Serious game design framework to teach hazard awareness and avoidance on construction sites using pre-defined hazard definitions. In C. Park, N. Dawood, F. Pour Rahimian, A. Pedro, & D. Lee (Eds.), *The future of construction in the context of digitalization and decarbonization* (pp. 348–358). (CONVR 2022 Conference : The future of construction in the context of digital transformation and decarbonization ; Conference date: 16-11-2022 Through 19-11-2022)

Yang, Y., Xu, Z., Wu, Y., Wei, W., & Song, R. (2021). Virtual fire evacuation drills through a web-based serious game. *Applied Sciences*, *11*(23), 11284-.

Zhonggen, Y. (2019). A meta-analysis of use of serious games in education over a decade. *International Journal of Computer Games Technology*, *2019*, 1-8.

10 Appendix

Observation Notes See external appendix A

AAU Facility Management Meeting Keynotes See external appendix B

Hovedstadens Beredskab Meeting Keynotes See external appendix C