User-Centered Product Design of Live-Action Game Experiences

by

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ABSTRACT

Recently, escape rooms, or live-action physical and mental adventure games that require players to solve puzzles and riddles to complete certain objectives in order to "escape" the room have been very popular. The design of this type of game demands knowledge and expertise in user-oriented product design in a live-action game scenario that engages and challenges participants of all ages. 5 Wits Productions is in the process of producing a live-action game experience based around dozens of "rooms" that each contain physical and mental challenges for small groups of guests to solve. Using the elements of user-centric design such as storyboarding and sketch modeling, a room theme was created and refined to give users a one of a kind experience that transports them to that theme. The theme was based off of the board game "Battle Ship" where players have to sink a ship using balls to defeat the game within the time limit. The final product was a display board ball detection system that showed the players their progress in the game and what areas they needed to hit in order sink the ships.

Thesis Supervisor: David Robert Wallace
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1. Introduction

Product design is traditionally known as the process necessary to create a new product to be sold to an intended customer [1]. The product design process is a set of tactical activities that will lead to the development of new products [2]. From idea generation to commercialization, product designers are tasked to combine science, engineering, and art to create a usable product that will, if successful, create an experience for its users.

However, product design isn’t only the process but the set of properties of an object (the product in whatever physical or electronic form ex. website, user interface) that describe its form and function [3]. The properties are supposed to instill an autonomic experience that illustrates what the designers intended use of the product is. Product designers use principles of industrial design to construct the form of a product [4]. By changing and experimenting ergonomics and the aesthetics of a product, product designers can create an expressive product that explains its purpose through just its use. In order to have a functioning product, engineering design also has to be utilized to create the technical capabilities of a product [5].

![Figure 1-1: The evolution of Apple’s iMac from beginning to now. Sleeker and lighter designs highlight the concept of form over function that product designers strive to achieve.](image)

As mentioned, utilizing the principles of industrial and engineering design will allow product designers to make products that will communicate a user-centered experience. This user-centric design has been applied to the plethora of products interacted with on a daily basis. Stoves, toasters, smartphones, and even in more abstract settings such as a ride at a theme park, have all employed aspects of user-centric design to transport and affect the user in an intended and creative way.

User-centric design has been widely utilized in physical entertainment centers such as amusement parks and fairs to give players an experience only previously imagined in movies and videogames. Recently, escape rooms, or physical and mental adventure games that involve players to solve puzzles and riddles to complete certain objectives in order to “escape” the room,
have been really popular worldwide. This increasingly popular type of game demands knowledge and expertise in user-oriented product design in a live-action game scenario that engages and challenges participants of all ages.

1.1 Live Action Game Experience

1.1.1 Escape Rooms

Recently, escape rooms have offered opportunities for user-centric product design to be applied in order to create engaging experiences for players of all ages. An escape room, also known as a “puzzle room” is a mental or physical adventure game in which teams of players have to solve various puzzles using strategic methods to accomplish the objectives of the room. These rooms have various fictional themes that carry a distinct plot that drives the type of challenges that can be encountered by players. This concept was implemented in North America by the company, 5 Wits, in 2004 and has since taken up a storm around the globe [6].

![Example of an escape room created by Ford in NYC.](image)

**Figure 1-2:** Example of an escape room created by Ford in NYC. The team of players have to cleverly navigate and strategically search the articles in the room to solve the objectives of the room.

1.1.2 Open-World: A Live-Action Experience

According to President and CEO, Matt Duplessie, 5 Wits Productions is now in the process of developing a live-action game experience, tentatively called “Open-World.” Players can navigate throughout an assortment of modular rooms that are intended to be quick mini-games, all with different themes and types of challenges, instead of the traditional escape the room that has
several challenges under the same theme and located contiguously. The rooms aren’t necessarily structured in the typical “escape-the-room” fashion and can be made to win a room with the intention of returning to that same room and scoring higher or passing onto a higher level. In order to successfully design, construct, and test one of these rooms the process of designing has to be applied to ensure that a breath taking live-action experience has the ability to transport players to a theme where they are faced with a variety of challenges.

![Figure 1.3: An example of a potential design of one of the modular rooms in the live-action experience.](image)

1.2 User-Centric Design

1.2.1 Product Design Principles and Human Factors

The challenging thing about designing a product and more specifically an experience is that there usually isn’t a clear right or wrong solution. Does it make a user feel a certain way? To what extent does it make the user feel that way? To what extent should the experience make the user feel? The boundaries are unclear, however there are three actions that if iterated on can lead to the successful implementation of a live-action experience for players. These three actions are to: ask, observe, and experience. Product designers have to pose questions about what the design of their product means and if the form and function they designed answers those questions. They have to observe how a user interacts with the product and finally they have to experience the product themselves and see where modifications are needed and beneficial [7].

An approach used in parallel is to have a set of guidelines that take into account human factors, or the science devoted to the study of interaction between people and equipment. This
helps prevent errors, avoid injury, and increases productivity of the both the design process and the final product being interacted with by people.

<table>
<thead>
<tr>
<th>Human Use Design Guidelines</th>
</tr>
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<tbody>
<tr>
<td>Avoid ambiguity</td>
</tr>
<tr>
<td>Avoid reliance on vigilance</td>
</tr>
<tr>
<td>Make actions and functions visible</td>
</tr>
<tr>
<td>Understand the users state-of-mind</td>
</tr>
<tr>
<td>Understand the users habits and patterns</td>
</tr>
<tr>
<td>Provide status information, cues, or prompts</td>
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<tr>
<td>Use direct metaphors</td>
</tr>
<tr>
<td>Strive for aesthetic minimalism</td>
</tr>
<tr>
<td>Use standards and be consistent</td>
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<tr>
<td>Design for error recognition</td>
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<tr>
<td>Recognition over recall</td>
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<tr>
<td>Instruct the user (form follows function)</td>
</tr>
<tr>
<td>Design for use conditions</td>
</tr>
<tr>
<td>Play the movie, do the experiment</td>
</tr>
</tbody>
</table>

Table 1.1: A common set of principles that are taught in design courses across MIT. The human use guidelines encourage efficient and cognizant design of a product or experience [8].

1.2.2 Communication of Design Experience

Coming up with a live-action experience starts at a rudimentary level that develops into a physical representation that instills certain feelings into a team of players. Physical deliverables and milestones were used to keep track and move forward the development of the final product. The first step taken was an ideation of different room themes and ideas that were narrowed down by criteria such as creativity, feasibility, and excitement for the theme. The next milestone was to sketch storyboards that showed the user experience of the theme and any gags needed to accomplish that. Once that was made, more detailed design experiences were drawn out to emphasize any concepts that might be critical to the room. Building on that, concept exploration models were made to physically grasp either the form or function of certain components of the room. This required practice in soft modeling to quickly and inexpensively tested intended key functions that might be difficult to answer in sketches or to refine form details, finishing methods, understand scale, and other human factors. Detailed design models were then made
using a variety of software programs to obtain a much more complete definition of both form and operation. This would eventually guide the building of the final prototype. The final milestone is the actual concept implementation that requires a fabricated prototype that realistically portrays the intended user experience. Choosing the proper colors, shapes, finishing and detailing techniques all play into crafting a prototype that reflects user-centric design.
2. Conceptual Design

2.1 User Experience Design (Storyboards)

Designing an open-world room requires exploring games, puzzles, and any special effects that the room might have. The most rudimentary way of designing a high-level user experience is to sketch a storyboard that lays out the plot and interaction that players will have with the room. This form of designing also helps refine ideation sketching skills.

More formally, a storyboard is a series of panels that depict key scenes, actions, visuals, and annotations that illustrate a user experience. The comic strip like panels can have annotations that explain, if needed, what the sketches are doing. Storyboarding is utilized in design studios across the world and for almost any type of user experience, ranging from movies, to games, to consumer products, to instructional design. Storyboarding in product design allows designers to focus on exploring and defining the user experience without getting distracted by feasibility and design of artifacts. Because storyboarding is sketching and intended to be quick, it is a really cost effective way to communicate a user experience without tedious and expensive prototyping [9].

An ideation session is necessary before starting to sketch a storyboard to narrow down and focus on a theme that is interesting and has the potential to have an engaging user experience. After a group ideation session, several themes were selected among the team such as: the butterfly effect, board games, toy shop, aerospace and illusions.

The butterfly effect theme was chosen with inspiration from science fiction films that show how a sensitive change in initial conditions leads to large difference in a later state. With the theme chosen, several room ideas can now be sketched. The interactions among the team and with the room are seen in the sketches as well as key details such as actions and visuals.
Figure 2-1: The first storyboard shows a team of players trying to escape a locked door that can be incrementally opened by solving small challenges on the way.
Team enters the room to find another room. They approach the small room to find a locked wooden door. On the outside room there is a set of switches. What are those shapes? What do they do?

When both switches are pressed, the room begins to rotate and the shapes from the small room become illuminated. The inside room has shapes on each of its walls. The outside room also has shapes on each of its walls.

The team decides to align the shapes on both rooms. The door magically opens. SUCCESS!

**Figure 2-2:** This storyboard shows a rotating room within a room that leads players to open a door in the smaller room by aligning the shapes and lights between the inner rotating room and the outer exterior room.
What the Bike
Team enters the room to find a stationary bike and a locked door with a keypad and a flashlight.

Step Switch: I
One of the team members points and grabs the flashlight and leads the rest of the group into the maze.

Step Switch: II
The team has to jump and duck under obstacles in the maze with little to no visibility. Be careful.

Use the Bike
The team presses the switches in different orders but nothing is working. Finally one of them decides to go back and start to pedal the bike with another member pressing both switches.

Stranger Lights
The lights under each letter start flicking in a pattern.

The Keypad
The code is for the keypad. The door slides open and the team can move on!

Dark Maze

Obstacles

Stranger Code
The team approaches the end of the maze and they see letters on the wall. Wait, they also see lights under each letter.

Figure 2-3: The final storyboard is inspired by the television show, Stranger Things. A team has to communicate together to navigate a maze, illuminate a panel that displays a message by pressing two separate switches and pedaling a bike simultaneously, and finally scream out a code that needs to be entered in a door to escape the room.
2.2 Concept Sketches

To further develop the interactive user experiences in the storyboards and to practice more advanced sketching skills, conceptual designs for a certain game, gag, or effect within one of the storyboards need to be created [10]. Upon receiving feedback for the team’s storyboards a theme was selected and new storyboards were made. The theme, “toys and games”, seemed the most promising and received the most interest from the team. Games such as Operation and Battle Ship offered interesting opportunities to show a user experience in a storyboard.

For example, “A Game of Operation” featured a life-sized rendition of the classic boardgame Operation where players have to use small metal tweezers to take apart “diseased” body parts without hitting the injured body of a patient. In this live-action example, there are levers located in different parts of the room that each control a certain motion of the operator arm. The team has to control the arm and navigate to the diseased locations to extract the malignant body parts. The team has to be careful not to rock the arm carelessly to avoid hitting the body and triggering the alarm that will mark the end to the player’s game. In order to fully beat the game the team has to drop the diseased body part into a bin that will eventually reset the pieces back into the body after each team leaves. The game can be structured to have a time limit where they have to remove all the diseases or it can be on a point system where they obtain certain points for every body part they remove correctly.
5 Minutes? The team enters the room to find an operating arm and a patient that seems ill. There are three levers on different sides of the operating table. The timer has begun. The patient only has 5 minutes left.

Lever 1: The first lever seems to move up and down. Upon inspection the team realized that the lever actually moves the operating arm side to side. This might get confusing.

Lever 2: Lever 2 is even wonkier. This lever controls the up and down movement of the operating arm.

Lever 3: The only thing left to control is the in and out movement. How does this cross pattern work?

Electromagnets: The timer is still ticking and the team only has a little over 3 minutes to remove all the viruses from the patients body. Note: The electromagnets are activated once they are close to the body part that needs to be removed. The spring connecting the magnets to the operating arm shake when any sudden movement is made.

Save the Organ: Once the virus object (metal) is picked up by the magnets, the team has to be very careful not to hit any organs (edge) on the side. Uh-oh, the team just hit one of the patient's organs. The metal made contact with the side edge of the organ and changed the resistivity of the circuit.

Flatlined: After hitting the organ, the team is alerted that the patient is long gone. The room starts to emit a flatlining sound and the table and room flash in red. Their time as surgeons is over. Note: The operating arm either relocates the virus back into the cavity or it will place it in the bin where it routes the parts into a system of conveyor belts and lifts that will place new viruses in the critical areas for the next team.

Operation Success: The team manages to take out all the viruses in the patient and put them safely in the bin on the left side of the operating table. The electromagnet only releases the piece when the coordinates of the operating arm are under those of the bins. The team successfully saved the patient's life in under the 5 minute time limit.

Figure 2-4: “A Game of Operation” is a life-sized rendition of the game “Operation” where teams have to rescue a patient from dying by removing malignant body parts carefully without hitting their body.

Three components of the room were highlighted to show in more detail the user interaction and working mechanics of the room. An important user experience of the story board is the use of the levers that control the operating arm. The user interacts with the exhibit via these levers, moving them back and forth along the machined path. As shown in Figure 2-5, the direction that the levers can move in, do not necessarily represent how the operating arm will move, confusing the team members and making coordination a difficult task. Two-point
perspective, or a graphic arts technique that is used to approximately represent an image as seen by the eye, was utilized to give the levers a realistic illustration [11]. Shading was used to make the cylindrical and spherical components of the levers pop-out into 3-D and tone was used to make the 2-point perspective even more realistic.

Figure 2-5: An important user experience of the story board is the use of the levers that control the operating arm. The user interacts with the exhibit via these levers, moving them back and forth along the machined path.

One of the features that isn't shown in the storyboard is how the resetting mechanism works when a team successfully positions all 3 "virus" pieces into the bin. The idea for the resetting mechanism is a conveyor belt system that routes the pieces to the three different critical positions and translates them into slots on an elevator pulley system that compartmentalizes the pieces into a small section on the elevator. When the game board resets, the next platform simply switches the new piece into the cavity of the patient's body part that needs fixing. The tone and shade of this concept sketch help give the drawing a realistic representation. Another approach to the resetting mechanism is to use gravity as much as possible to move the slots into the correct position and have them held by a peg, similar to balls in a skee-ball machine that are ready to roll down when released. Then a platform can be actuated to move vertically up and down once the body part is located after each team leaves.
The idea for the resetting mechanism is a conveyor belt system that routes the pieces to the three different critical positions and translates them into slots on an elevator pulley system that compartmentalizes the pieces into a small section on the elevator. When the game board resets, the next platform simply switches the new piece into the cavity of the patient's body part that needs fixing.

Figure 2-6: The idea for the resetting mechanism is a conveyor belt system that routes the pieces to the three different critical positions and translates them into slots on an elevator pulley system that compartmentalizes the pieces into a small section on the elevator. When the game board resets, the next platform simply switches the new piece into the cavity of the patient's body part that needs fixing.

The operating arm is the device that the team players have to operate to save the patient. Using the three levers at the different positions on the game board allow the team to move the arm in the "XYZ" directions to maneuver to the critical areas of the patient and remove the 3 diseased pieces. The inspiration for the design comes from 3D printer mechanisms and the idea is to have 2 electric motors control the side to side and in and out movements on the plane of the support mechanism and then possibly have an electric rack controlling the vertical direction (up and down). There will be wires running through the operating arm to provide a current for the electromagnets that will latch on to the virus pieces in the critical areas of the patient. Once the players successfully latch on to the piece they can start to move the operating arm into the bin. The piece will only be allowed to release if the arms end coordinates are directly under the bin.
Figure 2-7: The operating arm is the device that the team players have to operate to save the patient.

2.3 Concept Exploration Models

The concept sketches help detail an idea that wasn't shown in the storyboard. Concept exploration or sketch models are commonly used to explore and test ideas in conjunction with concept sketching [12]. Based upon another round of feedback given to the concept sketches, the next task in developing a user experience in the live-action scenario involves constructing these physical models that will help refine and test the potential of ideas and to obtain more information about the operational principles of the room. The sketch models can be divided into 2 categories: works-like and looks-like. The works-like model tests the operational and functional requirements or properties of a certain concept while the looks-like are used to define and refine form details, finishing methods, and human use factors. There can also be a combination of both where both form and function are being tested and analyzed [13].

Considering feedback and after team discussion it was decided that the best possible user-experiences would be either the Battle Ship or Laser Maze storyboards, storyboards introduced by other teammates. In order to decide what storyboard idea was going to be used in the final design, sketch models needed to be made for both storyboards to clearly see what user-experience would be the most involved and impactful on the players. “Battle Ship”, is basically a large scale version of the board game where players have to guess where enemy ships are located. In our full-scale version, players are given ammunition (balls) that will be tossed to other side in hopes that they can sink enemy ships. There will be a display board that marks where every ball has hit so they can aim in another direction to find the ships. Works-like models of the hit detection system and looks-like models of the display board were made to get an idea of the essential concepts of the room.
Figure 2-8: The looks-like model for the “Battle Ship” storyboard is the display board similar to the one in the actual game. There is a 4x6 grid with positions in the same spot as hit detection board where the team will be throwing the balls into. If there is a “ship” in the location they threw the ball in, then it will light up a red LED, otherwise it will light up a white LED recording that there is no ship in that location and that they should aim somewhere else.

Figure 2-9: a) The works-like model is the detection system that captures and records where a team of players throws a ball. Foam core was used to make the detection system. The floor of the detection system is angled to allow the balls to roll into the same corner and be detected. b) A contact switch was used to record and detect ball location. c) Prototyped circuit board of the works-like model.
The second storyboard is also a life-sized version of the slightly more uncommon board game Laser Maze, where players have to redirect a laser using mirrors to reach a certain target. The storyboard is demonstrated in Figure 2-10 through 2-16.

**Figure 2-10:** Team A enters a foggy room and notices 2 kinds of game towers: laser emitters and laser reflectors (mirror).

**Figure 2-11:** After the team sees a poster explaining the goal of the game they are ready to begin. The team realizes that they are playing a life-sized version of the board game, "Laser Maze" and that they have to redirect the laser to the target using the mirror pieces.

**Figure 2-12:** The team starts to move the mirror towers with the wheels!
Figure 2-13: The team discovers that if they hit a stationary mirror piece, it lights up green. This must be progress!

Figure 2-14: The team gets the laser to hit the target lights up green.

Figure 2-15: The team beats the game by using all stationary mirror towers and getting the laser to the target. Above is a top view of the board solved.
Figure 2-16: A camera overseeing the board sees that the game has been solved and signals the target piece to reveal the code to the door!

Works-like models include the Laser Maze Tower Positioning System that allows players to move the towers along a track in various fixed positions and the Laser Maze detection and reflection system which tests the feasibility of having mirrors redirected to a target that will detect a laser beam. The looks-like model is the Laser Maze Mirror Tower that deflect the laser.

Figure 2-17: a) Several handles were placed in different locations to see what location felt the most comfortable for users. b) Slits in the track were used to lock the movement of the towers on the track. c) The 45-degree angle is shown where the mirror would be fixed to deflect light at perpendicular angles.
The Laser Maze detection and reflection system which tests the feasibility of having mirrors redirected to a target that will detect a laser beam.

The game is centered around a team redirecting a laser to a target. The team has the option of changing the laser’s direction via movable towers (along a fixed track system) that have 45 degree angled mirrors on them. This tower, is the only piece that users interact with, and is thus in charge of moving along a fixed route and splitting the laser off into another direction when properly positioned. The construction of the mirror tower piece can be divided into three sections: scale, aesthetic design, and human use factors.

Figure 2-19: The Laser Maze Mirror Tower.
To ensure safety with players it was a requirement to keep lasers away from the eyes as much as possible so a tower height under most people’s eye level was chosen. The following scale represents the approximate scale that the tower will be when compared to a person.

![Figure 2-20: Laser Maze Mirror Tower Height.](image)

Most of the inspiration for the design of the tower was chosen around the theme of laser tag. In most laser tag facilities, guns and vests are transparent and allow users to see the exposed circuitry and LED lights under the devices. The finished prototype can be sheets of acrylic with a similar design engraved and illuminated by LEDs. Or if no electronics want to be used, the tower can be thermoformed out of one long sheet of plastic with this circuitry design engraved.
Figure 2-21: Circuitry design inspiration on the left and the actual design on the sketch model on the right.

Figure 2-22: The mirror piece is held elevated away from the tower to show users that the main goal of the tower is to utilize the mirror piece to redirect the laser beam.
Figure 2-23: The handle was placed on the tower to show completeness, but the actual position has to be determined to match where users find it more comfortable and intuitive.
3. Final Design

The work done in the ideation phase was used as a basis for deciding which of the concepts to pursue in even greater detail. Concept refinement requires making detailed design that will guide the build of the final prototype using digital modeling software such as Adobe Illustrator, SolidWorks, and Photoshop. Due to the complexity of getting the lasers adjusted and aligned to the target, the feasibility of the live-action game seemed very tedious and hard to implement. Therefore, the final design was going to be based off of the Battle Ship theme.

3.1 Concept Refinement

The goal of refining the concept is to establish the parameters and guidelines necessary to build the final prototype [14]. At this stage refining both the form or interface and the operation of the concept have to be polished and illustrated using digital modeling tools. Adobe Illustrator was used to develop the vision for the theme of the room, SolidWorks (computer aided design software) was used to make individual parts and an assembly of the critical components of the concept, and rendering software with SolidWorks was used to give a realistic view of what those components would look like in real life.

The room itself is divided into a couple of subsystems. The display board is showing the players the information necessary to strategically beat the game. It displays the grid locations where they have hit a ship and where no ship exists. The second system is the ball return mechanism which includes the parts that are visible to players and the mechanism behind the display board wall that is in charge of releasing balls one at a time. The final component is the 6x6 grid behind the display board wall that is in charge of detecting ball hits and funneling the balls out to the release mechanism.

3.1.1 Room Assembly

The storyboard illustrates a team of players facing off a navy battleship in a life-size rendition of the board game Battle Ship. Like the board game, the live-action room also has a grid that lights up to show the locations where players throw the balls in an attempt to sink the battle ships. When the ball hits a coordinate of the grid (behind the wall) that has a ship in it, then it lights up the corresponding LED red. If it lands on an empty grid it will light up white. On the right of the room they see a gun turret with ammunition ready for them to combat the ships. Figures 3-2 and 3-3 show the top and side views of what the room will look like along with the dimensions of the room. The total room length is approximately 10x17’, with about a 10x7’ space for the team to move around and aim the balls into the grid on the opposite side of the room, hidden behind the display wall.
Figure 3-1: Rendering of Room Layout

Figure 3-2: Top View of Room Layout
Figure 3-3: Side View of Room Layout

Figure 3-4 and Figure 3-5 show the room fully assembled.

Figure 3-4: Fully Assembled Room
3.1.2 Ball Release Mechanism

The ball release mechanism is connected to the 6x6 grid that is in charge of capturing the balls and recording where the team is planning their attack. It is connected with PVC joints of a diameter of 4.5 inches to fit the 3.5 inch balls. The balls are then funneled down to the release and held there by a mechanism similar to those used in skee-ball games. A peg is attached to a servo motor that rotates and allows the balls to move down to the players one-by-one. For accountability purposes the balls that are released during every turn need to be limited. Teams are only allowed one ball per turn (or throw). When
the servomotor receives signal from the IR sensor (in charge of keeping track of what “ship” is hit) in the 6x6 capturing grid, it will release a ball.

Figure 3-7: Ball Release Mechanism

As shown the balls are stopped and held in place with the release peg. Once a ball is sent down the tube and released by the servomotor it is fed down and through the wall to the second part of the ball release system that is visible to the team: the gun turret.

Figure 3-8: Ball Release Mechanism Assembly and Exploded View
The design of the room was based on the game Battle Ship so when designing the ball feeder that teams actually see, I thought it would be cool to have the “ammunition” dropped off of a gun turret that would be similar to something actually seen on a combat ship. The color scheme was based on the gray and cool colors of the game. The barrel of the gun turret would be a powder coated black to give an industrial appearance while the top of the barrel is a contrasting course aluminum cast. The turret has a raw magnesium cast color, again keeping consistent with the theme of gray colors seen on a lot of military ships. The turret feeds the balls into a basket forcing teams to reach down on the floor. The turret is connected to the ball release mechanism behind the wall.
Figure 3-10: Ball Release Mechanism Complete Assembly

Figure 3-11: Turret Assembly Exploded
3.1.3 Hit Detection System Grid

A critical part of the room is the determining which grid space a ball landed in after being tossed by the users. Figure 3-13 is a picture of the completed model, a direct translation of the grid that most are familiar with if having played battleship before.

The grid itself is 9x9', leaving 6" of clearance on each side for installation of the nets. These nets keep the balls in the modular live-action game and prevents teams from the launching...
the ball outside the room. As the grid itself is 6 x 6 squares, each is roughly 1.5', which correlates directly to the visuals presented to the users on the playing side of the room.

The physics of the grid is quite simple by taking advantage of gravity, all the balls can be fed back to the Ball Release Mechanism without the need of extra mechanical or electrical components. To achieve this, when a ball lands in one of the squares, it is immediately funneled to one corner as the entire grid is slanted here. The grid is constructed in a 2 floor system where the ball rolls down into the corner and then fall through a hole into the bottom most floor that is at angle and what causes the balls to funnel down to the Ball Release Mechanism. Detection of the ball is accomplished by an IR emitter/receiver that is installed directly over each hole much like an arcade basketball game; if a ball rolls into the hole, the IR device will be able to detect it and transmit the necessary info to the players on the other side of the board.
The entire apparatus is to be constructed out of wood for durability and structural integrity, with a damping material such as felt lined on the bottom of each square to reduce the coefficient of restitution of the balls. The balls should not bounce around the grid and should be dampened to stay in the grid that it was intended to be tossed in.

3.1.4 Display Board

The display board is the main source of information for users to understand the game. This board must clearly convey both the point of the game as well as information throughout the game for the players. The main feature is a 5x5' grid of 36 tiles. These represent the boxes behind the wall that the players can hit by throwing the ball into the corresponding locations. This causes the clear pegs protruding from the tiles to light up: red if a correct box is hit and white if the throw is a miss. This goal is displayed on the right hand side where the squares will light up if a throw lands in a correct box.

![Display Board Size](image)

**Figure 3-16:** Display Board Size
3.2 Concept Implementation

The final stage of the project involves fabricating a looks-like, works-like prototype of the idea described in the concept refinement. The final prototype needs to realistically portray the intended user experience of the live-action game. Importance to finishing and detailing is critical in order to make the prototype reflect high-quality engineering that effectively utilizes principles of user-centric and industrial design [15].

The implementation can be divided into 2 main sections: display board and grid detection system. In order to make the display board look as similar to the board game, a gun metal gray was chosen for the base color with a contrasting turquoise blue color on the grid elements. A hazy clear peg was used to indicate the position of hits that were thrown across the display board into the grid detection system. Those pegs light up either white or red depending whether a ship is “placed” in that position. Both the grid and the display board were made at half scale to ease with the prototyping but still allow for user interaction and proof of concept.

3.2.1 Display Board

The display board was made using a handheld CNC router called the Origin, made by the company Sharper. It allows pieces of any size to be cut precisely and accurately by importing an SVG file. Figure 3-18 shows the imported SVG file that was used to make the main wooden display board. The display board was made out of ½” plywood.

![Figure 3-17: Shaper Origin- CNC Router](image-url)
Figure 3-18: SVG File used to cut the display board figure into plywood. There are 36 grid holes in the middle forming the 6x6 grid of the detection system and 1 hole for the ball return as well as 2 holes to show the example of the hit and miss colors. The cut outs of the ship are intended to show what position of the boats are left to be hit in order to sink the ships.

The next step was to make the turquoise colored grid prisms that hold the LEDs and semi-transparent pegs. These would be made out of 1.5" thick pieces of 5x5" floral wet green foam. These were then painted using Montana Black Spray Paint- Cool Cologne. A hole was cut in the middle to fit the pegs. Once the pegs (semi-transparent plastic cups) were glued on from the inside, onto the grid pieces, the entire grid piece was hot glued onto the wooden display board. Stickers and graphics were added to the display board to give it a naval appearance similar to that of the board game. The cut-outs for the ships are illuminated by an LED strip that light up an acrylic panel when a player throws a ball into a grid position that has a ship.
Figure 3-19: The final display board is shown during a trial game. In the example above the lighted white pegs show a position on the grid that a player hit and failed to hit a ship. The red pegs show that a player threw and successfully hit a ship. On the right, the ship cut-outs are all illuminated to show that all 3 ships were successfully sunk.

Figure 3-20: Display board after players defeat the game within the time limit.
The display board is controlled by an Arduino Nano that sends the signals from the sensors and lights up the corresponding LED peg. A set of individual addressable LEDs were used in order to simplify the amount of circuit boards necessary to control everything.
3.2.2 Ball Detection Grid

The detection grid was made using $\frac{1}{2}$” plywood with the same half scale dimensions of the display board. The 6x6 grid was made with slanted inclines on every segment to ensure that the balls would roll down to the bottom corner where they could be fed back to players via the return system. The grid was made in two levels. The top level is the segmented grid platforms where the ball initially bounces onto and rolls down, into a hole that has the proximity sensors. The sensors transmit the ball location to the display board that then displays the information back to the players. The second level is an inclined platform that utilizing gravity leads the balls back to the return system.

**Figure 3-23:** Grid Frame

**Figure 3-24:** Top Platform showing ball rolling down.
3.2.3 Room Layout and Vision

In order to fully understand the design experience a 1:12 scale model was made to feasibly demonstrate the final design. The final assembly is also shown.

Figure 3-25: Top View Scale Model

Figure 3-26: Door Entrance Scale Model
Figure 3-27: Final Design Assembly
4. Summary and Conclusion

Product design is both the process and properties that develop the plan for creating an object (or service) that affords desired benefits to users. It combines science, engineering, and art to create a product that will instill an experience for its users. This experience is successfully created by employing principles of user-centered design, where the user is the driving force in all physical decisions that may influence them.

User-centric design has been widely utilized in physical entertainment centers such as amusement parks and fairs to give players an experience only previously imagined in movies and videogames. These principals have been expanded to escape rooms to give players a challenging, exciting, and memorable experience that makes them want to come back. This increasingly popular type of game demands the knowledge and expertise in user-oriented product design in a live-action game scenario that engages and challenges participants of all ages.

Through the use of storyboards, concept sketches, and sketch models, design ideas were explored and communicated. Themes were chosen after rounds of feedback that allowed the design of the room to be based off of storyboards for that theme. Once critical items of the room were tested and evaluated using sketch modeling, room ideas were narrowed even further to the single best idea.

The final stage in making a live-action user experience was to focus in on a singular room idea. This meant making detailed design models using a variety of software programs to obtain a much more complete definition of both form and operation. This would eventually guide the building of the final prototype. The final milestone is the actual concept implementation that requires a fabricated prototype that realistically portrays the intended user experience. Choosing the proper colors, shapes, finishing and detailing techniques all play into crafting a prototype that reflects user-centric design.

The final product was a working prototype of the room idea, “Battle Ship”, where players have to sink ships by throwing balls across a display board into a 6x6 grid that is hidden behind the display board. In order to transport players into the naval battle ship theme, the display board was decorated with dials and levers similar to what would be seen on a navy ship. The walls are painted to show enemy ships in the horizon.
5. Reference Page


6. ABOUT 5 WITS [Internet]. [cited 2018 May 7]. Available from http://5-wits.com/about/


