Shifting Planes: Envisioning Rock Climbing and Dynamic Movement in Mixed Reality

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Abstract

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Climbing is a complex and extreme sport. It is a battle of will, endurance, and strength to perform greats by defying gravity. The success of completing a climb encompasses struggles and many falls. Climbers will train constantly in order to climb to the top. A method of training for rock climbing often occurs through visualization of mental models. Climbers use mental models to define the hardest sections and places to strategically rest. This type of training is crucial to rapidly strategize solutions for competitions or for off-site practice. Mental models are an effective way to infer spatial relationships between recognizable landmarks such as holds. However, mental models lack complete accuracy. Mixed reality has the potential to support visualization training by bridging the gap between the mental model and the actual route. The combination of a physical mechanical wall and a digital overlay of a climbing route offers to bring mental models to a tangible space. This thesis envisions how rock climbing could utilize mixed reality to provide an experience that mimics the reality of climbing. Its intent is to support visualization training for climbers.

SHIFTING PLANES

Envisioning Rock Climbing and
Dynamic Movement in Mixed Reality

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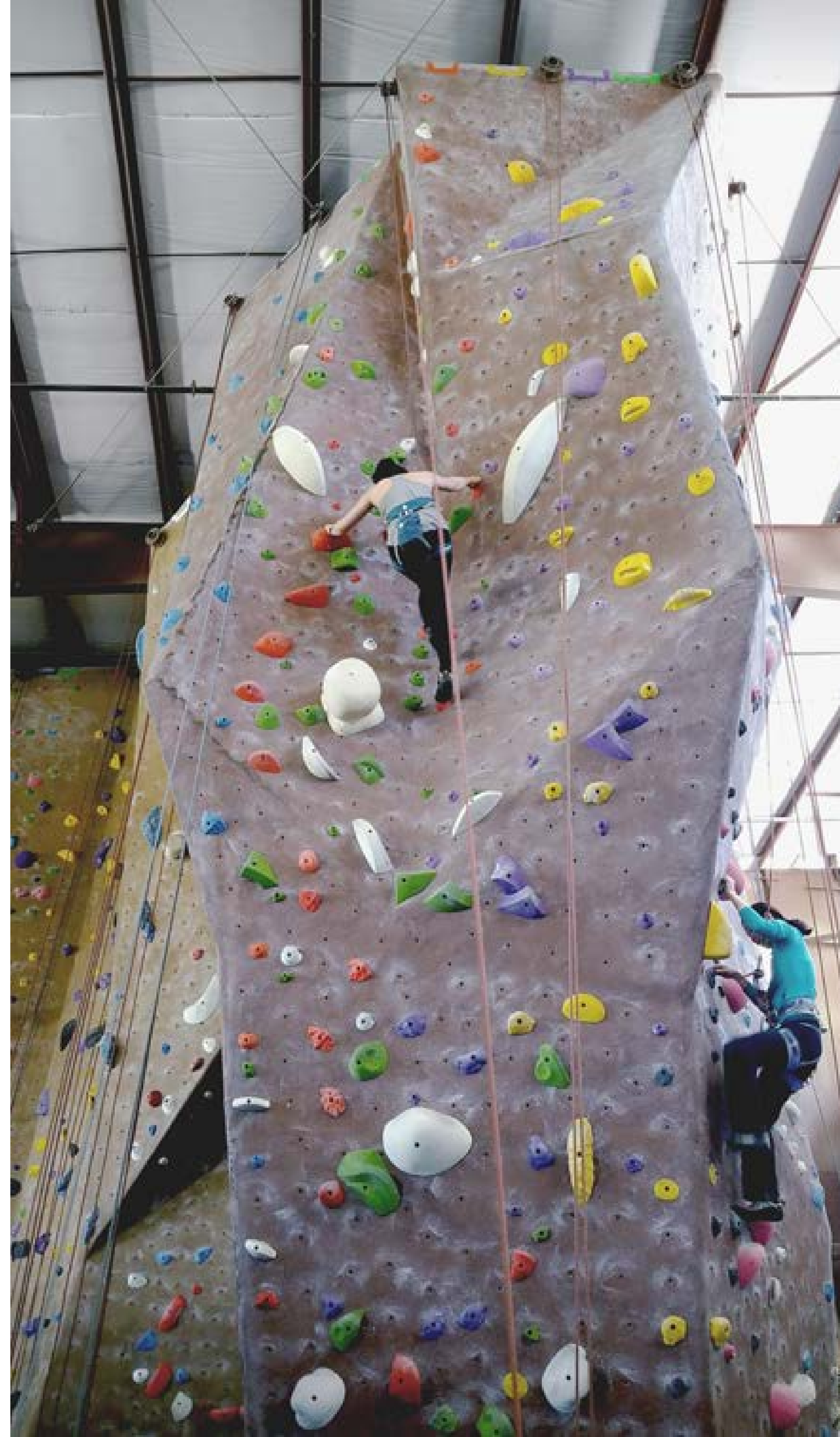
My first experience climbing was around 2015 or 2016. I had all these wild thoughts running through my head at the time. I remember my knees were quaking and the tension in my fingers as I desperately held on to the holds, high up on a 45-meter wall. I remember trying my best to not look down for fear of falling. I was actually quite terrified of heights. It's hard to imagine that after that experience I would continue to climb despite the fear. But finishing my first climb then subsequently experiencing the fear and frustration of falling after just being shy of a hold made my stubbornness kicked in. I was determined to successfully reach that hold. I was addicted, the sport of climbing had succeeded to draw me in.

This past spring, after a long break, a group of designers and I decided to go climb and challenge ourselves. I wanted to see how much further I could go. Eager to climb again and work our way from beginner status to advanced. We even wanted to become lead certified. To get the bright yellow badge that signified that we were officially advanced climbers. But this required great teamwork and trust in each other's ability to belay and catch falls. Working through tricky sections of routes by attempting to describe which possible steps and then as a climber trying to decipher it. We did always understand what was being said. Sometimes is took one of us to position our bodies to demonstrate what we meant. It is this experience and the love for climbing that made me consider how climbing and technology could intersect.



Climbing at Planet Granite, photographed in 2015

INTRODUCTION

Technology has made leaps in advancements in the last decade. The push to blur the boundaries of the physical and digital world has picked up momentum in last 2-3 years due to the interruption of COVID-19. With the pandemic stunting all person-to-person interactions, the drive to find remote collaborative tools became essential. One of those prominent pushes has been in the development of extended reality. Increases in investments towards virtual tools for entertainment, work, and education sectors has grown the industry from its niche position.

With the most recent introduction of the Metaverse and other industry adoption, Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) has proven that it could be a major player in interaction design.

What is Extended Reality?
Extended Reality (XR) is the umbrella term that encompasses Augmented (AR), Virtual (VR) and Mixed Reality (MR). Whether through a focus in one space or a combination, each aims to extend our realities by interacting with the physical or virtual world.

Augmented Reality
AR or Augmented Reality is the overlay of digital elements in the physical world. The most common use of AR is for marketing or mobile applications. Notable games like Angry Birds places or augments puzzles onto the desired environment of the person’s

choosing such as a deck or the floor and uses the cameras to place the digital element inside the digital bounding box or guardian. The guardian indicates the boundaries of the digital plane in relation to the physical world.

Mixed Reality

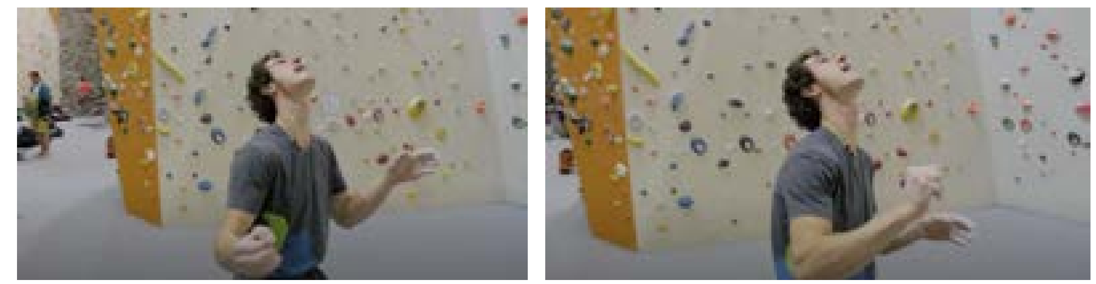
Mixed Reality works to extend realities by blending both the physical and digital world by placing the digital space over the physical. Both are able to interact and intervene with each other. Meaning physical objects could be used to anchor digital overlays into our world and align them. This provides a great space for simulation-based training. It provides the benefit of tactility that can enhance a digital experience.

Virtual Reality

VR or virtual reality is complete immersion in the digital space. Usually with wearables, such as head mounted displays or HMD, a person is transported into a fully immersive environment absent of any physical interventions. VR is nearly boundless. Creators and developers are able to place a person anywhere by design. Someone could be transported to South Korea while still in their living rooms touring the sites around Seoul. The Oculus is a version of a VR HMD. However, VR environments lack the presence of the physical world, moving around becomes difficult because the affordance to avoid physical obstacles become lost. To counter this, HMD often use guardians or a boundary for people to set. If someone steps outside of the guardian, a passthrough features is triggered to reveal the physical world and reorient the person's position.

Research around XR development has only scratched the surface of the potential for this space. Speech-based commands, gaze tracking, and line of sight displays are some areas currently being explored by researchers and designers. Mobiles, tablets, and head mounted displays (HMD) are devices used to experience AR/VR. Mobile phones are highly accessible, and industries favor this method for spaces like marketing. But screen base interactions don't quite make sense when interacting with a 3D object through a flat 2D surface. HMDs are useful for this reason because they lack the sole need to touch a screen in order to manipulate an object. Instead, people can utilize speech, gaze, and motion tracking to navigate. With the capabilities of HMD's layered with the capabilities of XR, the space the real potential to create experiences for many types of interactions like sports.

Climbing is a sport that includes Bouldering, Top Rope, Lead, and Free climbing. There are many more forms however, these are the most known. While these forms vary from each other, they all require a bit of problem solving to navigate their way to the top. Routes can be complex and at times climbers can get stuck. Climbers would typically fall once or multiple times and most often it is at the crux. Cruxes are the most challenging sections in a climb. They are the make-or-break moments that determine whether a climber succeeds or not. Success or sending as it is called, is defined by a climber completing a route in one go without falling. To work through these, there are two possible paths that climbers can use visualization and beta. Climbers can often be seen hand gesturing and memorizing the route over and over



Adam Ondra visualizing a route, scenes from Adam Ondra #39: Visualization: A Crucial Part of Climbing

until they can visualize it in their mind. This is especially common during competitions. Adam Ondra, one of the greatest climbers in the world, talks about the importance of visualization. In his video, "Adam Ondra #39: Visualization: A Crucial Part of Climbing" discusses his method of training. Visualization helps to define where the crux points and where the strategic points of rest are (Adam Ondra, 2019).

The method of visualization and mental models help climbers to map out the spatial relationships of holds. By doing this, the act reveals indications of where and how to move. Although not entirely accurate, it allows climbers to navigate their path by way of landmarks or holds. Mental models become a frame of reference for climbers to practice their movements. Eventually these mental models become collages of maps based on the different perspectives of experience or termed Cognitive collages. Cognitive collages is a collection of reference points based on the inference of landmarks from various perspectives that become more accurate as more information is digested (Tverskey, 1993). In other words, a climber's mental model will adjust accordingly as their perspective of the holds change.

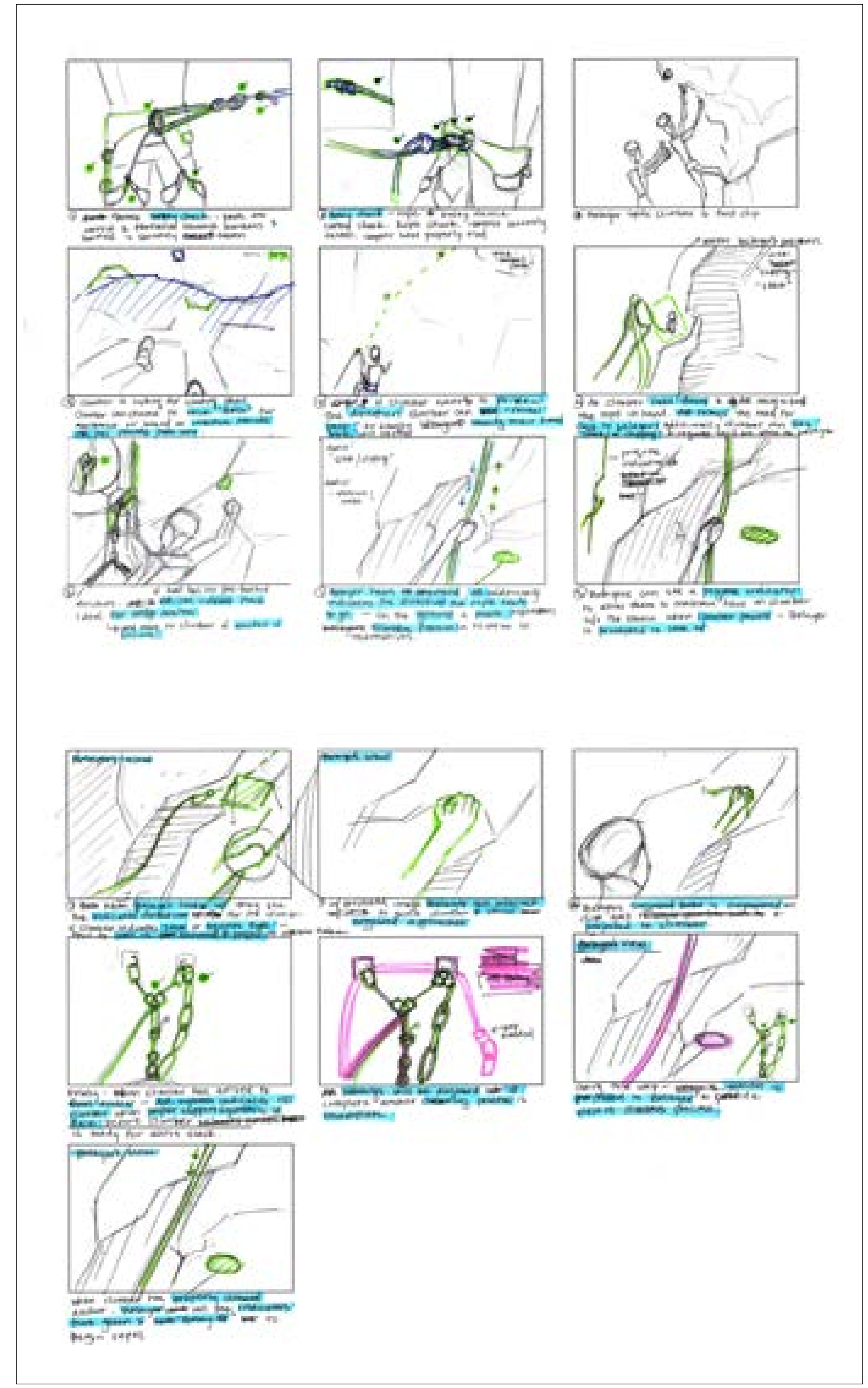
The other method, beta, is the solution to the problem. Climbing is a community sport, in gyms, it's often common for other climbers to discuss moves for certain routes. Most times, it is a discussion between the climber and belayer. For certain forms of climbing such as Top Rope and Lead, a belayer is needed to harness the climber to the safety system. Top Rope is where the rope the climber is tied into is anchored at the top of the route. This mean the belayer really only has to pull the excess rope or slack to provide tension to suspend the climber. Lead is the opposite, the rope is only tied into the climber and throughout the route, the climber needs to clip in the rope to the anchor system using quickdraws. The belayer is tasked with providing slack so as not to pull the climber off with too much tension.

The climber and belayer can sometime be seen working together in order for the climber to get to the top. During cruxes, when a climber is stumped, a belayer can offer verbal suggestions help the climber along. But the communication can be somewhat cumbersome. Climbing like all sports has their own set of jargon, however if you don't know the jargon, talking through suggestions can be convoluted. Often times it consists of describing the look of the hold and the approximate location to the nearest limb. This can take time for the climber to calibrate and follow through but eventually the climber is able to finish the crux.

Both methods provide interesting spaces to explore how XR and rock climbing could intersect. With MR capabilities, it is possible to take the mental models and the gesturing to a tangible space. Because of the use of both physical and digital worlds, there is potential to provide a training experience that could support climbers. On the other hand, the relationship of the climber and belayer and the method of communication felt like a space that could explore multisensory interactions. AR could possibly provide a diagram or markers to support quicker and clear comprehension. What if there was a way to use the technology to overlay different perspective to show what the other person sees, and would this be helpful to minimize loss in translation? How could we display this time of information? This thesis aims to explore and envision how rock climbing could utilized the space of extended reality to create methods wayfinding. Wayfinding in context of communication or simulation.

Storyboarding

I initially started by storyboarding a climber's journey. This was great way to help define a starting point. I was really interested in the relationship between the climber and belayer and the layers of communication that existed between them. A belayer is the person who is responsible for the climber's safety, they hold the other end of the rope and prevent the climber from falling too far when they do, and it tends to involve some communication. I wanted to discover if there was a seamless method that would allow the two to overcome the barrier of distance and perception to facilitate clear verbal exchange with minimal cognitive load. One those ways was to consider AR technology to projects or overlay the climber's view to the belayer.



Storyboard sketch of a possible AR and rock climbing scenario

RESEARCH

Existing XR Research

In order to begin considering how to use AR to achieve clear climber and belay communication I also needed to understand the capabilities of AR technology and how it was currently being utilized. AR has the potential train fine motor skills, in one study AR was used to train students how to insert a needle into vessel by projecting internal mappings onto a mannequin (Rochlen et al., 2017). Although not completely accurate, it showed that training for detailed task was at least possible.

Other studies that look into the use of AR/VR to design wayfinding aids through complex environments and expand to allow navigation through multiple floors (Kim et al., 2015). Additional studies have looked into wayfinding through speech-based navigation and the perception of distance (Feng et al., 2006). This gave insight to how directive communication should be considered between two people. However, these studies only considered horizontal navigation or moving up and down one horizontal plane to the next.

Bock et.al looks at vertical navigation through a different lens. The research was to see if vertical navigation was possible and if a person's orientation was obstructed by navigating through a virtual maze. What they found was that participants were relatively able to still navigate through a vertical maze almost as well as a horizontal one (Bock et al., 2020). The possibility of true vertical navigation wasn't far off.

In the space of extended and climbing, current products focus on enhancing the climbing experience through gamification. By adding competition, sensationalism and/or customization, users can essentially exercise while having fun in within the convenience of their home or climbing gyms. But it leans away from a classic climbing experience. Other research has been conducted to explore rock climbing with a virtual overlay onto a physical wall (Kosmalla et al., 2020). Kosmalla et. al looked to use proxies as most augmented walls focused on enhancing the boards or using remote controls to manipulate the climber's body. They used physical holds as markers to map in a virtual environment (VE) which was projected onto a wall. This provided tactile feedback while seeming to climb a realistic rock wall. The research of combining the physical with a VE provided a basis to explore as a possible avenue to consider.

Experiments

Over the following weeks, I conducted several field experiments. These were conducted in hopes that the experiments could reveal possible directions and approaches to methods best suited for this type of sport. Especially an activity that requires hand-free interaction.

Two Person Camera View

In the initial phase of the field research, to observe the different view from the climber's vs belayer's perspective the participants wore GoPro cameras and strapped it to their heads. I wanted to have the camera match their line of sight (LoS) as close as possible to mimic what the climber and the belayer were seeing. Both views were time synced and laid out side by side. These are the discrepancies revealed between the two perspectives:

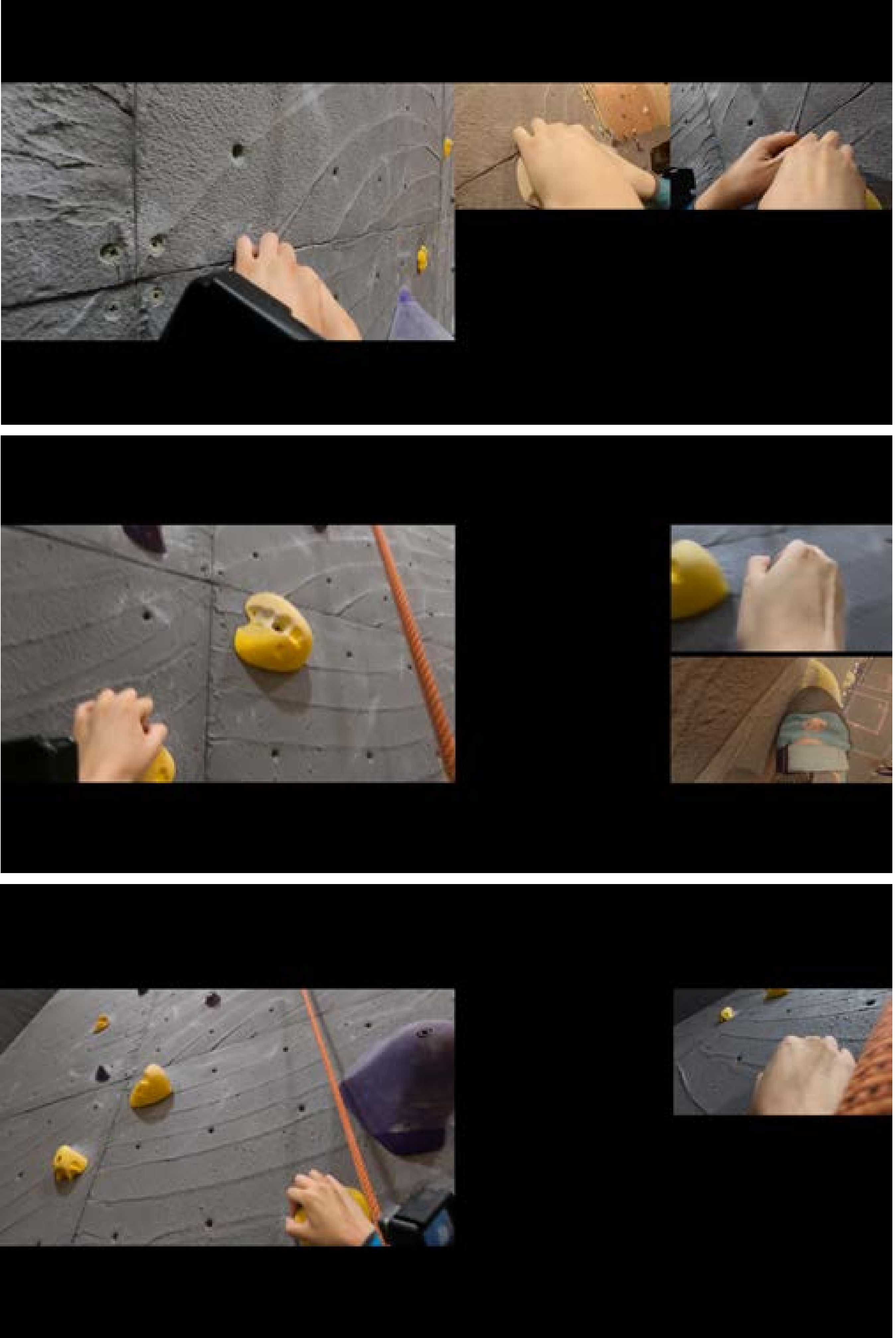
Climber:

- The climber sometimes tests their grip on each hold before proceeding. A seemingly good hold can turn out to be terrible once the climber has received tactile feedback from their fingers or toes. A hold is considered good when the climber has relatively easy placement to grip and provides some resistance where a bad hold can be slippery, shallow, flat, or even smooth.
- The severe upward angles can make holds look deceptively good until the climber places their hand or foot onto the hold.
- The position of the hold that can stump the climber and require testing out different positions. Distance can also be an issue for the climber. From a certain distance, a hold can be perceived to be closer until the climber attempts to reach for it.

Belayer:

- The downward angle they're positioned in tends to skew their ability to accurately estimate the proximity of a hold to the climber.
- The provided beta can be quite difficult for the climber to accomplish due to the foot hold being too high or the hold being too far. It isn't until the climber attempts to do the beta does the belayer get a better indication of distances.
- The belayer's ability to assess a good vs bad hold is skewed because of the severe angle of their LoS. Until the climber places their hands or feet on the hold can the belayer properly assess the quality. This falls in line with Knapp and Loomis' study on perceived egocentric distance(Knapp & Loomis, 2003) from the observer's perspective. The distance and angle is not favorable for the belayer to accurately measure an object.

Preparing the camera setup for the experiments, photographed by Vassilissa Semouchkina



Screenshots from the Five Camera View video compilation

Five Camera View

Expanding upon the insight from the initial exploration, I decided to have 5 cameras attached to the climber to provide line-of-sight from the hands and feet. I discussed how the climber needs tactile feedback to assess the quality of the hold or to measure the distance. Therefor it seemed to make sense to record from the perspective of the hands and feet. The fifth camera was mounted on the head.

Each video alone did not reveal much, when viewed at the same time, it was completely overwhelming to watch and impossible to analyze. However, when the videos were curated to show hand or foot movement in-sync with the field-of-view from the head's line-of-sight, it revealed possible opportunities to consider. The following insight was gathered from the curated recording:

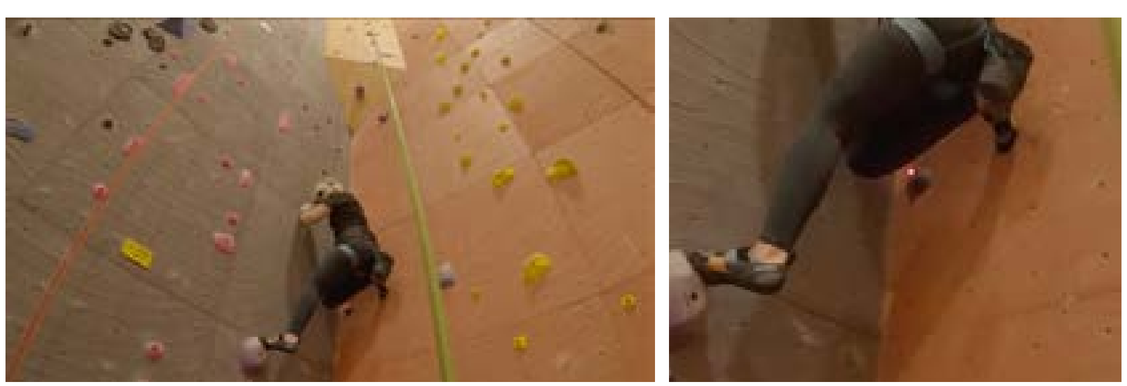
- The climber is only able to move when they perceive with their hands and feet that their placement is steadfast and that their balance won't be compromised.
- The climber used their eyes to anticipate action while their core, hands and feet were used to follow the action through.
- The cameras and rope obstructed each other so the climber had to reassess hand placement due to this. Any camera operated system would need to be lightweight and extremely compact in order for climbers to possibly consider wearing extra gear.
- FOV would need to be wider as the videos were too tightly cropped in, preventing the viewer to garner any additional information from the recordings.

Laser Pointer Beta

Some of the friction that comes from climbing is the belayer's inability to clearly relay beta due to a number of reasons. The lack of the full climbing jargon like matching, gaston, dyno and the level of noise can often contribute to the difficulty of communicating with the climber. To overcome this, a simple laser pointer test was conducted to see the effects of having a direct mode of pointing.

This is not a new method. Climbing instructors would use a laser pointer to help young students figure out a solution to a problem. But I felt it necessary to try it out with participants to get a first-hand observation. The exploration revealed the following:

- The belayer was able to concentrate mostly on the safety of the climber and less on describing moves to them.
- The laser pointer was quite effective in directly communicating beta to a climber. The belayer could quickly point to a hold, and the climber would immediately follow through.
- It optimized the time it took for the belayer to describe the look and the proximity of the hold. Therefore, the climber no longer needed to process and translate what the belayer was relaying and could simply look for the indicator.
- While it doesn't eliminate all the friction it revealed that direct mode of pointing on the wall alleviated some of the indirect interaction.
- However, the belayer must always have both hands or a break hand on the rope at all times. Therefore, it was inefficient for the belayer to hold the laser pointer while managing the rope. This leads to the necessity of having a hands-free interaction.



Screenshots from the Laser Pointer experiment

Lead Class

The final exploration was receiving lead climber/belayer certification. This involved taking a three-day course over a three-week period to learn how to clip the rope in, falling safely and proper belay techniques.

From the lessons, I learned that at both ends, the climber and belayer's list of roles and responsibilities increased in comparison to top rope. The climber has to always be aware of the way they clip into a quickdraw. Should the climber clip in the wrong side of the rope or the wrong direction through the clip, this could cause some serious issues. If the climber falls, the rope could release from the quickdraw and cause the climber to fall farther or create issue for the belayer to lower the climber safely. They must also reassess their climbing technique since they release one hand off the wall in order to clip in their rope. Therefore, they must find optimal balance to safely do this.

The belayer's cognitive load has also become greater. With top rope, while it is important for the belayer to always watch the climber, they are able to take a more relaxed approach. The risk of falling is much less than lead. In lead, the belayer is mostly feeding rope to the climber, but they must pay attention to how much slack is given at all times. Since there must almost always be slack, this means that the height of the fall for a climber will be greater. Belayers must always assess the position of the clip in relation to the climber's harness to understand how much or how little slack should be given in case of a fall. Both hands at all times must always be on the rope, the break hand is especially crucial as there is little preventing the rope from sliding through the belay device.

Observing this, it is my opinion that any intersection of AR technology but not provide greater cognitive load to what is already presented. It must work seamlessly into the existing workflow without much disruption in order to provide effective communication between the climber and belayer. In this next section I discuss the major points of insight revealed through the experiments.

RESEARCH ANALYSIS

At the start of this thesis, I was mostly interested in the communication between the climber and belayer. But the findings revealed a few findings that particularly stood out. Balance and body positioning were important, tactility plays an integral part, climbers navigate with arms and legs, and a climber's movements are often precise and intentional.

Balance and Body Positioning

Navigating in a vertical fashion requires strategic movement and balance. Climbers are constantly working against gravity. If a climber is off balance, it is usually due to an uneven distribution of weight caused by miscalculated body positioning. It is usually suggested the climbers keep their hips close to the wall and their core tight. Using this technique helps prevent the climber from wildly swinging and being pulled off the wall.

Climbing at a slow and steady pace while maintaining an even weight distribution is a highly effective strategy that allows the climber to expend less power (Sibella et al., 2007). One of the best technical climbers in competitive climbing is Jain Kim. She is known for her perfect climbing technique (Albert Ok, 2020; Ascentionism, 2021). She is able to constantly maintain her balance by taking her time and readjusting her positions as she moves (Ascentionism, 2021). Each move is calculated thereby maintaining controlled balance.

Tactility as integral feedback

Hands and feet are a climber's guide to the stability of their grip. Through the 5-camera experiment, the recordings show that oftentimes a climber will adjust their position based on their confidence of their grip. This can be affected by texture, distance, angle, and depth. Tactility influences how a climber calculates their proceeding movements. Inference is taken from the types and combinations of holds thus allowing the climber to react accordingly (Sibella et al., 2007). This includes adjustment in position for stable equilibrium or proceeding movements. Such aspects like friction and depth indicates how much weight support is afford, thereby affecting the climber's movements(Sugi & Ishihara, 2021).

Through observation, there were moments where the climber gave cause to test the way the grips were held. Maneuvering their hand in specific ways to assess optimal grip. Once the climber received confirmation, they were able to proceed onto the next step. In fact, it is the combination of the tactile feedback from both the hands and feet that provide necessary information for better assessment.

Arms and Legs as Measures of Distance

A common theme of observation that emerged was the climber's ability to navigated based on the climber's ability to reach the next hold. At the ground up, climbers first assess the route scanning and gathering information about the difficulty base on the distance and size of the holds. Additional assessment is needed once a climber is in proximity to a hold. This is due to the skew of depth perception and distance from the severe upward angle the route is initially viewed from. As stated by William H. Warren Jr., in Self-Motion: Visual Perception and Visual Control "Affordance set the boundary conditions on possible actions. Realizing a particular affordance —stepping over or steering around an obstacle—requires further perceptual guidance" (Warren, 1995). Meaning, holds provide points of reference for distance and depth, however upon approach new or a change in possible actions requires adjusted information. This is a common action by climbers, Adam Ondra briefly mentions after mentally working through the route through gesture, finds that sometimes he would perceive sections that seem like good resting zones only to realize differently upon closer inspection (Adam Ondra, 2019).

Distance is measured by the span of their reach. What could be perceived as closed together could actually by far apart. Upon a closer inspection, climbers would have a better frame of reference from the reach of their arms and legs to measure distances.

Intention and Precision

A culmination of the previous three insights suggests that a climber's movements are made with intention and precision. Maintaining balance and stable positioning while gathering tactical and proximal information shows the complexity of rock climbing. Each insight integral to the success of the climber. Climbing at times can be compared to the movement of cats. Every movement they make is with intention and purpose.

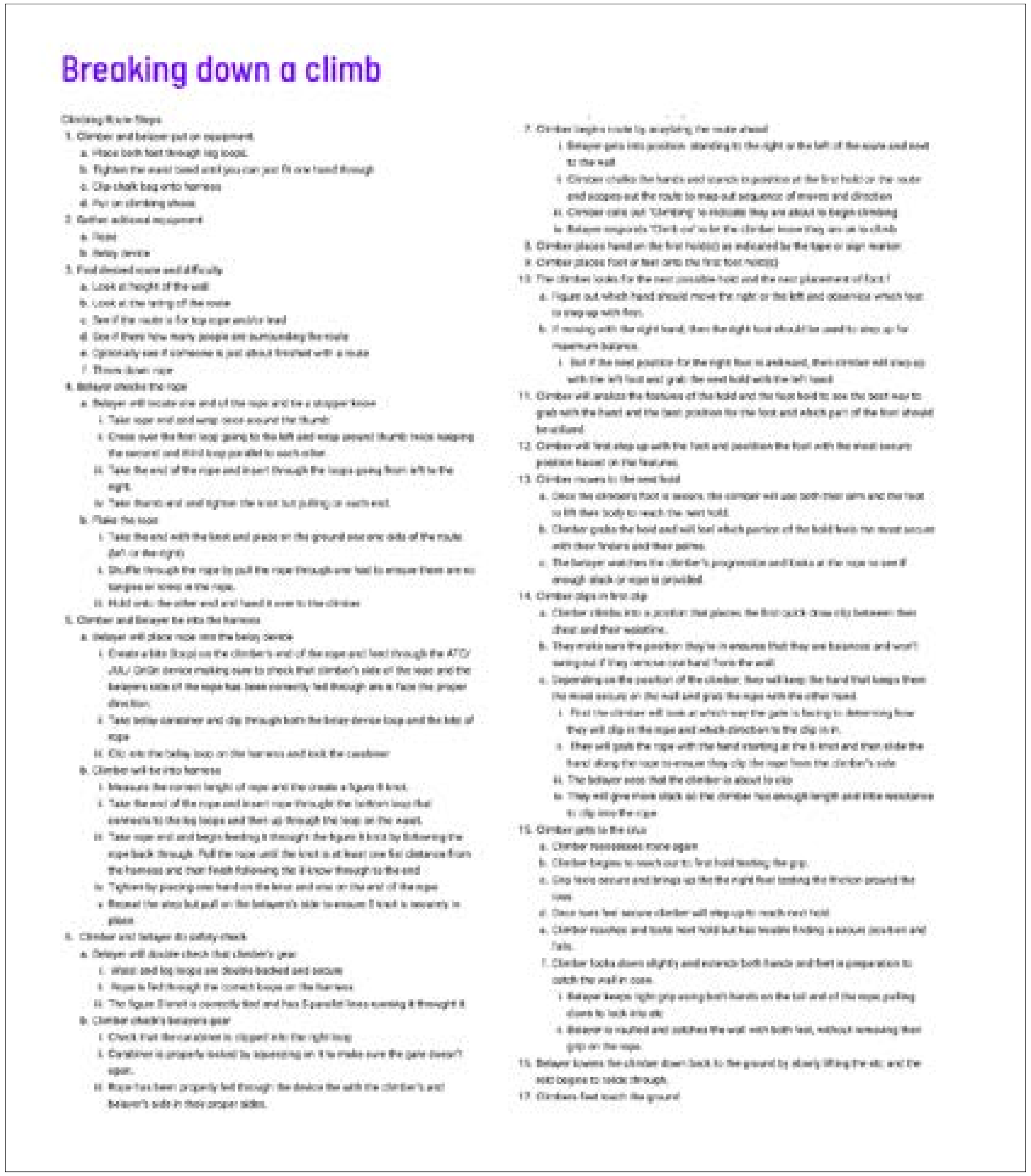
Based on these findings, thought my thesis intended to focus on the communication between the climber and belayer using AR to facilitate clearer beta. Though line of sight and communication are important, verbal communication becomes less integral to a climber's advancement. As a climber advances, they are no longer dependent on the belayer for assistance. Rather, they become self-reliant on their own abilities to work through the route. The findings led me to realize that my original question had not fully considered other and more prominent aspects in climbing. I needed to reassess and ask better questions. To do so, I reexplored the climbing scenario and broke down each step in greater detail by writing the process out.

Breaking Down a Climb

Through this exercise was the steps that required the climber to read and reassess the climbing route. This resonated as it reminded me of the visualization training that climber often do to work through their movements for a route. I questioned how we can better support this mental model they create.

When we consider the difference between indoor and outdoor climbing, climbing indoors is not always a one-to-one experience with outdoor climbing. In fact, I would argue that it can be quite different if you were to look at the holds used commonly in indoor climbing. The holds are less similar to the pockets and holds you would see on a rock wall. Therefore, training for outdoor climbing in an indoor gym, doesn't entirely make the most sense. Gyms can still set crux movements to mimic the movements of an outdoor route and sometimes professional climbers have the ability to route set in their own space, making training still possible. But this is not accessible to everyone, nor does it always make the most sense to do. For this reason, I wanted to focus my thesis on training for outdoor climbing in an indoor setting, using VR and a physical component to closely simulate the outdoor climbing experience.

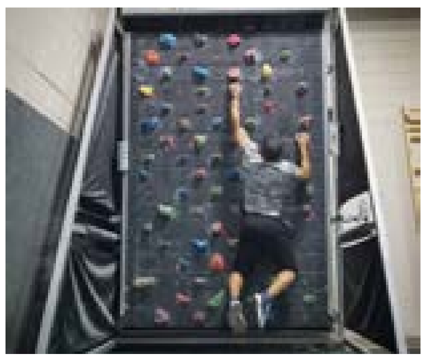
I was mostly inspired when I was watching a short documentary by Reel Rock Films of climber Margo Hayes trying to send (to complete in one attempt) a 5.15 climb. In one clip she shows a paper diagram of all the marked holds on the route. She is seen reenacting each and every movement by moving her hands in the air (REEL ROCK, 2021). This moment made me ask, why couldn't we make it more accessible for climbers to train for a particular route without the need to wait for a gym to route-set the movements or to wait until the climber is able to journey out to the site. Could we make a simulation using a combination of a mechanical climbing wall and a VR overlay to create a training tool to allow climbers to easily access various outdoor climbs and practice?



DESIGN PROCESS

In reference to the findings from the earlier experience, it was clear that tactility could not be compromised. In order to provide effective support, the overall experience needed to emulate the reality climbing as close as possible. This mean that a physical intervention was valuable to the experience. Due to this factor, it made sense to shift from an AR to and MR experience. This would allow the consideration of incorporating a physical artifact to provide the benefit of feeling weight and resistance while being immersed in a digital environment.

Additionally, climbing is a vertical sport, unlike the way we walk, climbing requires the use of both hands and feet. Meaning the experience needed to account for the use of feet. This was further validated through The Importance of Virtual Hands and Feet for Virtual Reality Climbing, written by Kosmalla et. al. (Kosmalla et al., 2020) Through their investigation, they conducted a series studies to test the efficacy of including feet virtual representations for virtual climbing experiences (Kosmalla et al., 2020). The inclusion of feet is crucial. As mentioned in the findings, the feet help to provide a sense of balance. They also act as receptors picking up tactile feedback to indicate whether the body position is stable or not. The exclusion of feet increased the margin of error when stepping in the visualizations (Kosmalla et al., 2020). However, the virtual representations of the hands tend to remove the virtual experience from the physical. It is important for the virtual experience to consider cutouts of the hands and feet to minimize the gap between virtual rock climbing and the reality of it.



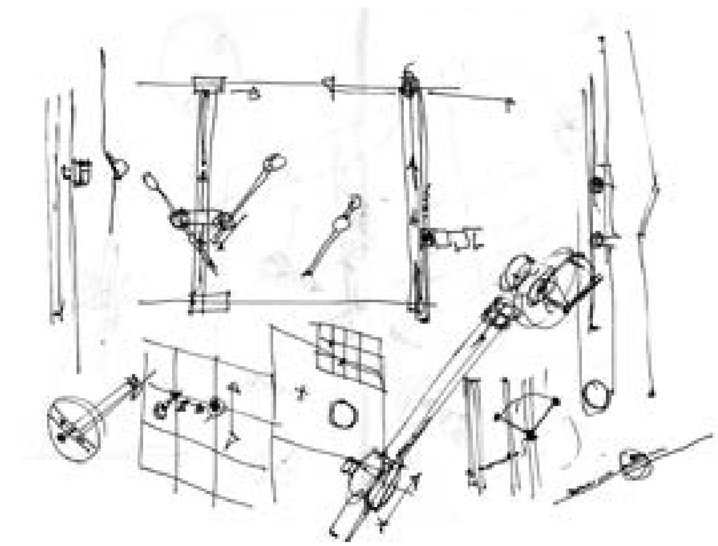
Treadwell Rotating Climbing Wall

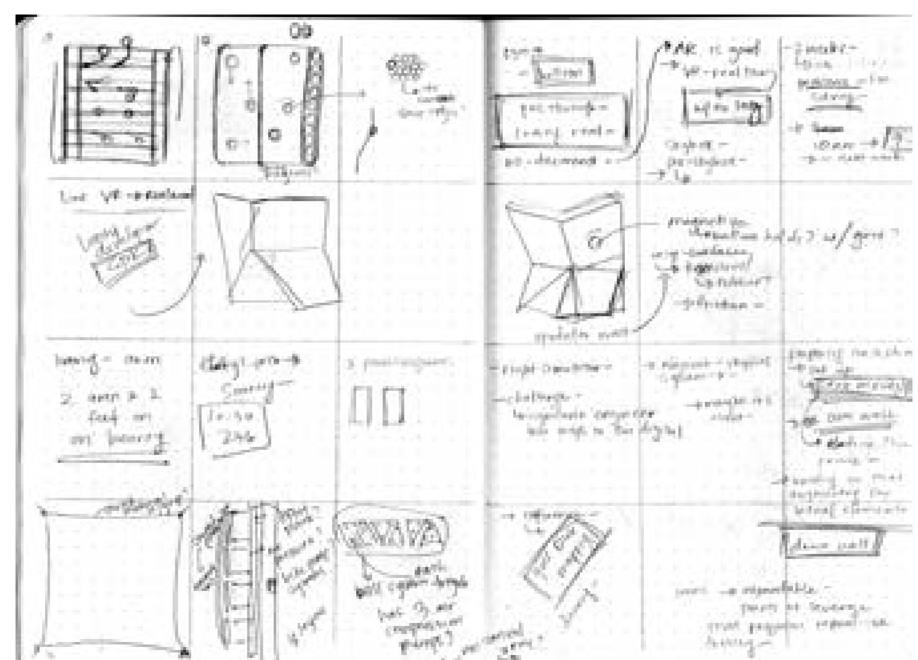
Rock Climbing Technology

As a starting point, I look into existing rock climbing technology. I started looking into climbing treadmills because they allowed for continuous movement which was beneficial for compact mechanical systems. The downside of such systems means that the same pattern of climbing holds were rotated repeatedly. Other such systems used body weight as a means to create momentum, however this could hinder a person's ability to learn proper body positioning. A mechanical version with shifting holds that could possibly move to match positions on a climbing route could improve the treadmill system. This would eliminate the need to manually switch out the hold in order to set a new route, rather an automated hold would not require manual input. The addition of a virtual environment overlayed onto the wall using an HMD could provide a climber's the ability to train for outdoor climbing routes in an indoor setting, pick up where climbers left off and provide a tangible space for mental models to exist.

Brainstorming

I knew at the start that I needed to ideate a wall that could live in an indoor environment. If this wall was going to be housed indoors, it needed to be reasonably simple. To figure out some possible directions, my committee members and I did a quick sketch session to brainstorm ideas.

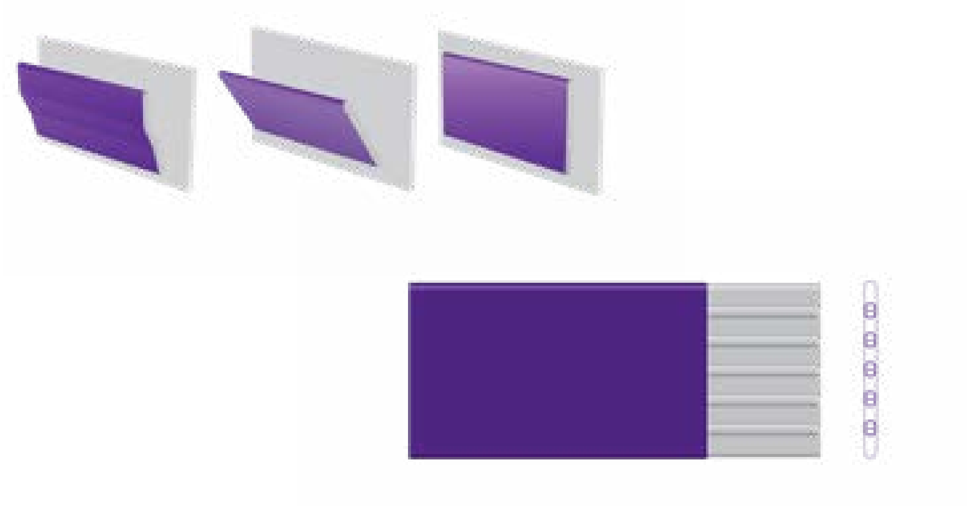




Brainstorming Sketches made with committee members

Jacobs Ladder Treadmill Wall

Ideas varied from a mechanical treadmill that bent and transforms similar to a Jacobs Ladder toy. Comprised of long panels connected with long cylindrical joints covered with thick rubberized material. The concept was to create an updated treadmill system that could create fairly simple versions of complex overhangs and would use magnetic holds that would rotate and move around the wall. However, the holds movement could be hindered due to the bends of the wall joints.



Ideation of Jacobs Ladder Treadmill, created in Illustrator

Paneled Kinetic Wall

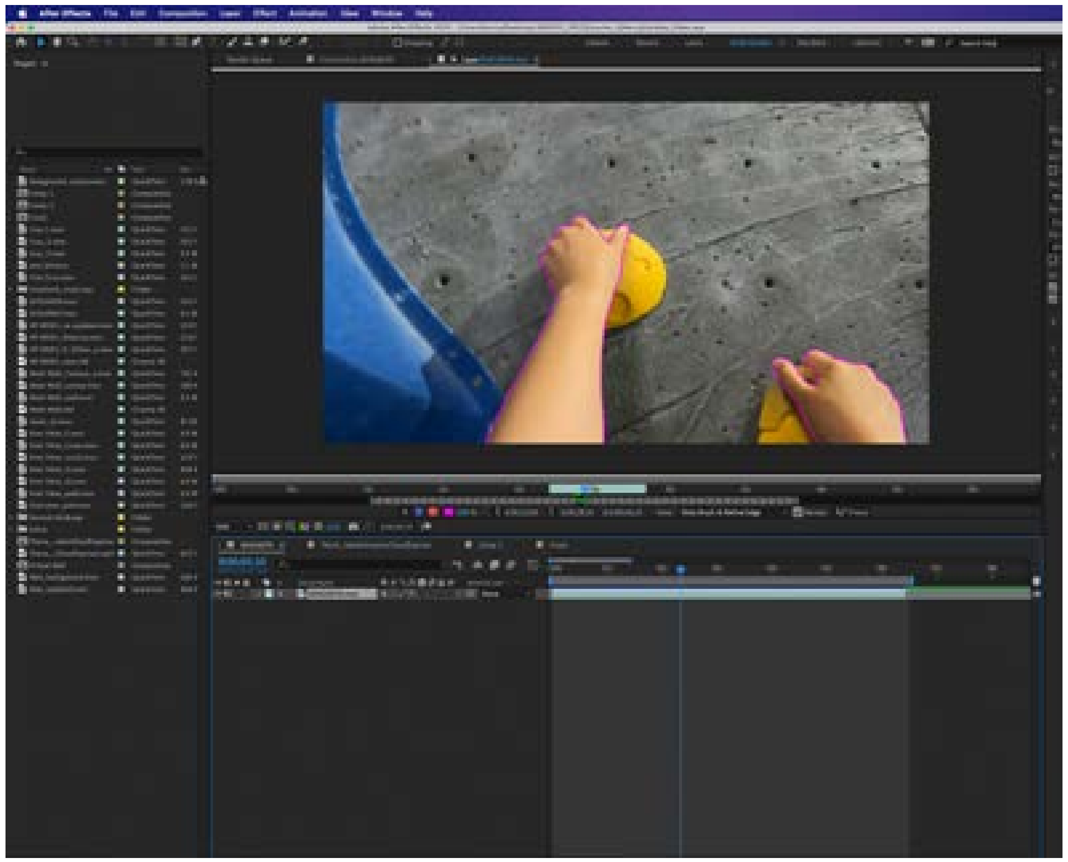
A secondary idea consisted of a series of triangle panels on a climbing board. Each panel would be connected by a set of three rods for each point that would extend and contract. The inspiration behind this was origami architecture. Origami folds allow for extremely complex creases that create complex structures. Rock faces are amorphous surfaces that have many nooks, crannies, cracks, and facets. A paneled concept seemed to consider the complex surfaces of a rock face. However multiple moving parts could create an overtly complicated system and the spaces between the panels would also cause issue to moving holds
Each of these concepts also require extreme mechanics that quite honestly would take a lot of space to house the mechanics. The operating systems to develop such concepts would be financially burdensome. What it boiled down to was figuring out a mechanism that wouldn't rely on advanced mechanics. Where I ultimately ended up was the idea of a mechanical wall with 8 moving rods— four for the hand and four for the feet— that would expand, contract, and move around on a simple track system. Covering this system would be a thick stretch fabric to act as a protective barrier. Over the fabric, holds would be magnetically attached to the 8 rods.

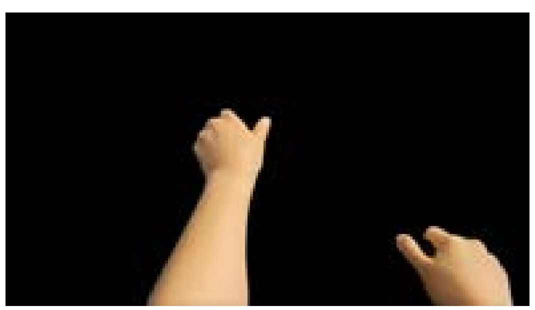
Creating the Visualization Concept

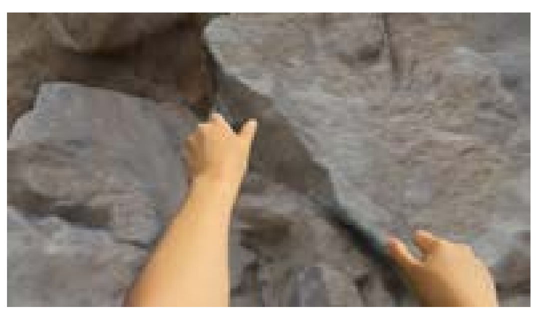
Since I had the wall mostly defined at this point, I proceeded to consider how I would communicate this concept to the audience. The goal of the visualizations was to envision how training for rock climbing could potentially harness the capabilities of mixed reality. In essence a climber would be physically scaling the mechanical wall while virtually ascending an outdoor route. To further specify, the focus could be to train around the crux. This constraint is in place because often times a climber is tripped up at the cruxes and require one or more attempts to successfully overcome the obstacle. And a video was an effective way to communicate this concept. It allowed me to visualize the relationship between the virtual space, physical wall, and the climber.

In order to have the best possible chance at creating a better experience, I purchased a high-poly rock wall rendering (3D Scan Cliff Wall Model - TurboSquid 1646770, n.d.). This saved time and allowed me to concentrate visually communication the overall experience. Scanning the 3D render, I needed to do a little route setting and plan the path that I would have the actor follow. The hope was to create a path where I could mimic the movement in real like and then sync the motions up. The challenge was finding a similar enough route in a climbing gym and hope that the recorded climb would sync up without too much issue. From there I had the climber wear a GoPro camera strapped to their head so I could capture the moments the hands connected with the holds as well as the head movement.

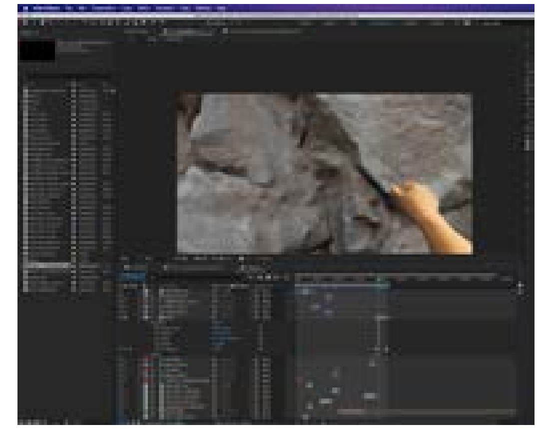
Image of marking out the route on 3D model and a behind-the-scenes shot

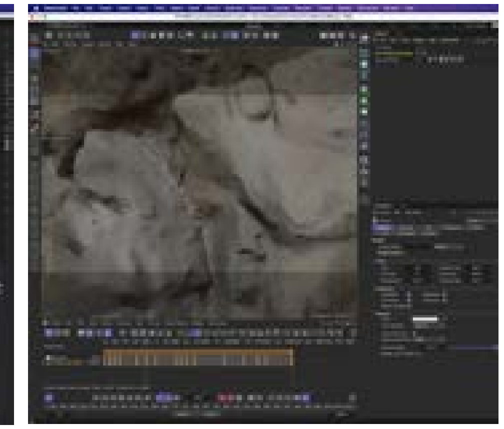






Process shots of masking in After Effects and then layered over a 3D render





Animating the camera in Cinema 4D to match the vdieo recording

The recordings were taken into After Effects so I could mask the background. This gave me the control to select the hands and cut out the wall. I did this because a climber visualizing their own hands and feet would help to minimize the separation between the physical and virtual world. With the rotobrush tool I was able to select the areas that needed excluded by drawing a stroke over the hands and arms. Rotobrush allows for automated masking meaning that one frame is used as a reference point and then calculates all the location of the selections in the rest of the frames. However, this method is by no means precise. Some frames had the wall and the hands selected while others had partial selections of the hands. After the general selection had been made, I proceed to adjust the selection boundaries frame by frame, so they were cleaner. Once the backgrounds were fully masked, I could move on to adding the layer of the 3D model.

The next step was to layer in the digital background. To achieve this, I actually need to operate Cinema4D at the same time as After Effects. After Effects has an extension link the two applications together, creating better workflow to review camera animations live. This can often slow down the processing which increases the amount of time it takes to render out a scene. But it provided reference for controlling the camera rigging. Using the applications side-by-side allowed me to figure out how and when to zoom in/ out or rotate the camera rig to mimic the head's movement in the recording.

Visualizing the Mechanical Wall

The next challenge layering the mechanical wall into the video. But concept of the wall was still hard to grasp. The idea was all in my mind however attempting to synthesize the idea onto screen was quite tricky. What I ended up doing was creating physical models of the mechanical wall. By going through this process of building the models I was able to get a better gauge to the scale and the way the rods could operate. With this concept I came to understand that to achieve overhangs and more extreme positions, rather than a massive wall that was tipped and suspended, only the necessary rods would need to extend out to achieve the same thing. The models were made up of a back wooden panel and 8 dowel rods cut to various lengths. Each rod was glued and secured on to the panel to mimic various climbing positions.

After the panel portion was complete, I needed to sew the fabric covering for the 'mechanics' of the wall. Using about a yard of stretch polyester, I cut it down to 3 pieces measuring 11 x14inches. The fabric was hemmed to prevent any tearing and then punctured with grommets to create attachment points. I initially tested it out to see how it would look before proceeded to the rest of the build. Using loaded hooked springs and tiny eyelets, I attached and stretch the fabric over the rods to create the desired effect. The holds were made using Scupley a type of polymer arts and crafts clay to create tiny circular holds. After curing, the attachments were placed on to the dowels over the fabric. Finally, I attached three action figures to finish off the models

The process of building these models helped to create a more concrete and tangible form for the wall. It allowed me to define what the form of the mechanical wall would ending up being. I needed to take this idea and place it into the video to provide some context to the interaction. At first, I considered using video to record the motion with a set of wooden chopsticks and stretched out black fabric. But this posed a challenge and was not quite suited for the video. After the physical models were models, I was able to use it as reference to create a simple model of the wall in Cinema4D. Using the same method as the rock wall, I animated the camera movements to align with the first portion of the video where it was featured.

Physical mock up of the Mechanical wall

Syncing the video and the mechanical wall render

Henry Installation

At the end of this making process, I showcased the video alongside the 3 physical models. It was important for the audience to see the potential this interaction could have. The mix of the physical and digital wall. The models provided contexed to the video and the video helps to provide context around the models. I also felt it was important to include my own rock climbing gear to show implications of the process and personal connection behind the installation. Together it is my hope that people were able to imagine what a climbing experience could be like how the importance of tactical feedback.

Henry installation photographed by Julian Body

DISCUSSION

Rock climbing is an intense and complex sport. It requires excellent balances, technique, precision, and self-awareness to the body's reactions. It is a sport that provides risk, challenge and intrigue that tend to draw in many people. Throughout this entire process, there were the key takeaways that I learned about climbing and digital experienced.

- Hand and feet coordination is incredibly important to navigating inside an immersive experience. It is also important to minimizing the gap between the digital and physical comparisons.
- Future rock climbing experiences need to provided minimal lag. Rock climbing requires precise movement to make proper and correct contact to holds. Therefore, if there is a disconnect in the speed of how the physical body moved and the way it is digitally visualized that the experience will feel disconnected.
- For dynamic movement it is important for the person to see their hands and feet. This again speaks to the potential to disconnect the two experiences between the virtual and physical world. To minimize the calibration, need to adjust to the speed of virtual hands and feet, it stands reason that providing the climber the ability to see their own would provide better spatial context.
- Tactility is crucial to a complex interaction like rock climbing. It is integral to the training process and provides necessary feedback.

Each of these points should be considered for future experiments around physical activity simulation. The use of mixed reality helps to ground the user to the virtual experience using physical artifacts to help imitate the genuine real-world experience.

Future explorations should also consider the types of hold for the mechanical wall would be beneficial to this concept. The is a discrepancy between indoor gym holds and natural rock face. Climbing gyms commonly use sports style holds while natural rock face usually consists of pockets and cracks. The type of holds can bear a lot of influence to the movement of the climber as well.

Other considerations could also continue to explore other forms of the mechanical wall. There are some limitations to much the concept can account for interms extreme overhangs. Positions that place the climber flat on their back maybe difficult to achieve without articulation in in the rods. This might cause some fragility to the structure. Therefore continued iterations should still be considered.

CONCLUSIONS

Envisioning the future of rock climbing and mixed reality is only the starting point for future potential in extended reality. This thesis works to consider the value and nuances of visualization training by considering the power of mixed reality. The benefits of using the combination of physical and digital elements to create a dynamic method for climbers to train off-site. Mental models are a common method of training and can be effective for a multitude of sports. And has been proven to be an effective method. To take that one step further, mixed reality has the capabilities to support and provide a tangible space to the model.

Mixed reality provides a space to create interactions that have potential to provide genuine experiences in the future. And the advantage of leveraging tactile feedback is a huge benefit. With mixed reality, there are real possibilities of bridging the gap of experience in immersive environments. Additionally, affording people to see their own hands and feet affecting, interacting with the digital space would work to provide a better bridged experience. As mixed reality technology advances, so too must the experience that is provided. Designing experience would no longer need to create flat screen-based interaction but rather interactions that are more intuitive to how we interact with the physical world.

During this thesis, I really learned a lot about the relationship between the digital and physical world. It helped to illustrate the possibilities this space has to offer and how far we can really imagine future interactions. There are endless possibilities and implications for augmented, virtual, and mixed reality. There are many layers and facets too. This thesis helped me to navigate just the surface of what those could be. I also learned a lot of new software along the way. However, sometimes rather than using the high-tech applications, it helps to create and work with your hands to help work through undefined spaces. With the capabilities and future vision for mixed reality, the ability to create with your hands and in the digital space seamlessly could be a future opportunity. To bring tangibility to the ideas that are still in our minds.

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