Title
Incorporating Sound and Acoustics into the Reconstruction of Archaeological Landscapes

Author
Goodwin, Graham

Publication Date
2024

UNIVERSITY OF CALIFORNIA, MERCED

Incorporating Sound and Acoustics into the Reconstruction of Archaeological Landscapes

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

in

Interdisciplinary Humanities

By

Graham Goodwin

Committee in charge:

Professor Holley Moyes, Chair
Professor Jayson Beaster-Jones
Professor Nicola Lercari
Professor Michael Spivey

Professor Jeff Yoshimi

Dedication Page

I would like to dedicate this dissertation to my lovely wife Cyndi who without her love and support this dissertation would not be possible.

Table of Contents

Lists of Symbols, Tables, Figures, and Illustrations

CERTIFICATION OF APPROVAL

INCORPORATING SOUND AND ACOUSTICS INTO THE RECONSTRUCTION OF ARCHAEOLOGICAL LANDSCAPES

By

Graham Goodwin

Dr. Holley Moyes | Date

Dr. Nicola Lercari | Date

Dr. Jeff Yoshimi | Date

Dr. Michael Spivey | Date

Dr. Jayson Beaster-Jones | Date

Acknowledgements

I would like to acknowledge the guidance and feedback of Dr. Holley Moyes as well as the rest of my dissertation committee. I would also like to recognize the constant love and support I received from my wife Cyndi throughout the dissertation writing process. Finally, the help and encouragement of both my parents and in-laws helped make this all possible. In addition I would like to recognize the valuable feedback and guidance I received from graduate student Joshua Clingo in the creation of the VR experience.

Curriculum Vita, Publications, and Field of Study

EDUCATION

Expected Summer 2024 PhD Interdisciplinary Humanities University of California, Merced Major Advisor: Dr. Holley Moyes

2023 MA Interdisciplinary Humanities University of California, Merced

2018 MA Anthropology University of Nebraska-Lincoln
Major Advisor: Dr. Heather Richards-Rissetto

2015 BA Archaeology Willamette University

RESEARCH EXPERIENCE

School of Social Sciences, Humanities, and Arts University of California, Merced CA
Graduate Student Researcher May 2022–August 2022 (20 hrs a week)

- Provided expertise in geospatial methods for a public health research project funded by the Center for Disease Control.
- Created visual representations of key structural factors in Merced and Madera Counties, identified relevant data, and created high resolution maps.
- Developed project visualizations and data analysis.

School of Social Sciences, Humanities, and Arts University of California, Merced CA
Graduate Student Researcher May 2020–August 2020 (20 hrs a week)

- Operated and applied WAVE (Wide Area Visualization Environment) Virtual Reality system.

Department of Anthropology University of Nebraska, Lincoln NE
Graduate Researcher Assistant June 2017–July 2017 (40 hrs a week)

- Created image-based models of artifacts and architecture at the ancient Mayan city of Copán in Honduras.
- Instructed students from the University of Tegucigalpa in photogrammetry.
- Recorded ambient audio for Virtual Reality and 3D modeling.

Midwest Archaeological Center National Park Service

Archaeology and Collections Intern May 2017–December 2017 (30 hrs week)

- Organized and managed collections from the Menard-Hodges site in Arkansas Post National Memorial, Gillett, AR.
- Performed research and cataloged Mississippian period ceramics, lithics, and artifacts.
- Created image-based models of ceramic shards and faunal remains.
- Employed image-based models for conservation, reconstruction, and analyses.

PROFESSIONAL EXPERIENCE

School of Social Sciences, Humanities, and Arts University of California, Merced CA
Graduate Teaching Assistant August 2018–Present (20 hrs week)

- Grade, review, and provide comments on assignments, quizzes, tests, and essays.
- Hold office hours and assist students enrolled in the class.
- Responsible for teaching individual labs and leading discussion sections.

School of Social Sciences, Humanities, and Arts University of California, Merced CA
UROC SURI Graduate Research Mentor May 2022–August 2022 (20 hrs week)

- Served as a mentor for undergraduate students participating in summer research projects with U.C. Merced faculty.
- Held office hours and met with students weekly for discussion and project evaluations.
- Led discussion groups and lectured on topics relevant to academic research and attending graduate school.

REFEREED PUBLICATIONS

Richards-Rissetto, H., Primeau, K. E., Witt, D.E., and Goodwin, G. (2023). Multisensory Experiences in Archaeological Landscapes—Sound, Vision, and Movement in GIS and Virtual Reality. In: Landeschi, G., Betts, E. (eds) Capturing the Senses. Quantitative Methods in the Humanities and Social Sciences. Springer, Cham. https://doi.org/10.1007/978-3-031-23133-9_9

Goodwin, G. and Lercari, N. (2022). Reconstructing Past Phenomenology Using Virtual Reality. In Horizons of Phenomenology: Essays on the State of the Field and Its Applications. New York: Springer Academic Publishers. New York. https://library.oapen.org/handle/20.500.12657/62410

Goodwin, G. and Richards-Rissetto, H. (2021). Modeling acoustics in ancient Maya cities: Moving Towards a Synesthetic Experience Using GIS & 3D Simulation. Digital

Archaeologies, Material Worlds (Past and Present) (pp. 73–86). Proceedings of The 45th Annual Conference on Computer Applications and Quantitative Methods in Archaeology edited by J. Glover, J. Moss, and D. Rissolo. Tübingen University Press. https://doi.org/10.15496/PUBLIKATION-43230.

HONORS, AWARDS, AND FELLOWSHIPS

Summer 2023 Luce Fellowship, University of California-Merced.

Spring 2021–2023 Fellow in the Spatial Archaeology Residential and Online Institute, Center for Advanced Spatial Technology, University of Arkansas.

Fall 2016 Champe-Weakly Research Fellowship, University of Nebraska-Lincoln.

Fall 2016 Edgren Tuition Fellowship, University of Nebraska-Lincoln.

INVITED TALKS

2024 Multimodal Digital Documentation of Actun Tunichil Muknal, Belize. Dominique Rissolo, Holley Moyes, Justin Simkins, Kay Vilchis Zapata and Graham Goodwin. 89th Annual SAA Meeting. New Oreleans, LA.

2019 Multisensory Experiences & Narratives in Archaeological Landscapes – Sound, Vision, and Movement in GIS and Virtual Reality. H. Richards-Rissetto, K. E. Primeau, D. E. Witt, and G. Goodwin. Computer Applications and Quantitative Methods in Archaeology (CAA) international conference. Krakow, Poland.

2019 Hegemonic Architecture in Late Classic Copán. G. Goodwin. 8th Annual Meeting of Interdisciplinary Humanities Graduate Student Conference. Merced, CA.

2018 Modeling Sight & Sound in Ancient Maya Cities: Moving Towards a Synesthetic Experience using GIS & 3D Simulation. G. Goodwin, H. Richards-Rissetto, K. E. Primeau, and D. E. Witt. 138th Annual Meeting of the Nebraska Academy of Sciences. Lincoln, NE.

2018 Bringing Sound into the Picture: Experiencing Ancient Maya Landscapes with GIS and 3D Modeling. G. Goodwin, H. Richards-Rissetto, K. E. Primeau, and D. E. Witt. Computer Applications and Quantitative Methods in Archaeology (CAA) International Conference Symposium, Sensory GIS: towards a deeper engagement? Tübingen, Germany.

2018 Soundscapes and Visionscapes: Investigating Ancient Maya Cities with GIS and 3D Modeling. G. Goodwin, H. Richards-Rissetto, K. E. Primeau, and D. E. Witt. 83rd Annual Meeting of the Society for American Archaeology. Washington, DC.

2017 Making 3D Models from Photos: Teaching Photogrammetry to Honduras' First Generation of Archaeologists. H. Richards-Rissetto, C. Juckette, and G. Goodwin. University of Nebraska Department of Anthropology Fall 2017 Semester Colloquium Series. Lincoln, NE.

2017 Image-based Modeling of Artifacts from Menard-Hodges. G. Goodwin. 74th Annual Meeting of the Southeastern Archaeology Conference. Tulsa, OK.

2017 3D Simulation of Acoustics in Ancient Maya Architecture. G. Goodwin and H. Richards-Rissetto. 125th Annual Meeting of the Nebraska Academy of Science. Lincoln, NE.

2017 Modeling Acoustics in Ancient Maya Cities: Moving Towards a Synesthetic Experience Using 3D Simulation. G. Goodwin and H. Richards-Rissetto. 45th Annual Computer Applications and Quantitative Methods in Archaeology. Atlanta, GA.

2015 Elemental Characterization of Roman Imperial Coinage from the Hallie Ford Museum Using Portable X-Ray Fluorescence. G. Goodwin. 44th Annual Meeting of the Classical Association of the Pacific Northwest. Portland, OR.

TEACHING EXPERIENCE-UC MERCED

ANTH 001. Introduction to Socio-Cultural Anthropology
ANTH 003. Introduction to Anthropological Archaeology
ANTH 005. Introduction to Biological Anthropology
ANTH 010. Quantitative Methods in Anthropology
ANTH 149. Forensic Anthropology
ANTH 152. Death, Dying, and Dead Persons
GEOG 002. Introduction to GIS
GEOG 112. GIS for World Economic History

Abstract

This dissertation focuses on the creation of a Virtual Reality (VR) model of the ancient Maya cave site of Las Cuevas, Belize. The theoretical framework for this dissertation is one of digital phenomenology, in which digital methodologies are used to support phenomenological archaeology approaches. A brief history of phenomenological archaeological is provided as well as critiques of the approaches. However, it's importance to this dissertation project is emphasized. Archaeological data is well suited to 3D representation especially when incorporated in a VR environment. It is further enhanced by the addition of sound to the VR environment. Data for the environment is provided by simultaneous location and modeling (SLAM)-based Lidar data that was collected at the site using an Emesent Hovermap over the course of several days during the 2022 field season. To complement the 3D environment of the cave, sounds were also recorded within the cave as well using handheld recorders. The result was a detailed mesh model of the entrance chamber of Las Cuevas along with environmental features such as water and bats. This was turned into a VR experience that could be explored using an HTC VIVE headset and controller. After the creation of the experience, it was utilized in an experiment with two participant groups. One group experienced the VR environment with sound, while the other without. Surveys were conducted of participants and user movement in the environment was tracked. Results were inconclusive, but promising and showed that sound created a more engaging and immersive experience.

Chapter 1: Introduction

The increasing adoption of geospatial technology in archaeology is documented in a growing percentage of published archaeological literature (McCoy 2021). One key area of geospatial technology is high density survey and measurement (HDSM) instrumentation known as Light Detection and Ranging, or LiDAR, acquires geospatial data useful for understanding how people experience the space and form of archaeologically relevant material and landscapes (Opitz and Limp 2015). Importantly, this data can be presented at a scale relevant to human experience, creating the opportunity for using HDSM data in phenomenologically focused research such as modeling soundscapes in virtual reality (VR) to better understand experience. However, VR experiences have primarily been utilized for simulating movement in combination with visual experience (Opitz 2017). Yet, humans are spatial beings and sound is inherently a part of spatial perception, making it interconnected to space and form (Eisenberg 2015).

I used Unreal Engine 5 to reconstruct an ancient Maya archaeological cave site that was utilized in an experiential focused experiment as an example of how HDSM data from an archaeological research project can be successfully integrated into a singular virtual environment at the scale of individual human experience. Engaging with this environment as an immersive virtual reality (VR) experience is a novel way to present archaeological material or phenomenon (Tost and Economou 2009). The medium used to present the data also affects how it is perceived (Di Giuseppantonio Di Franco et al. 2015).

Immersive VR conveys some spatial attributes of the soundscape more effectively than others, but this area would benefit by further research. Research on how people experience VR reconstructions that are grounded in geospatial data from archaeological and cultural heritage projects shows promise (Pujol-Tost 2017; 2018; 2019; Pujol and Champion 2012). This dissertation focuses on utilizing HDSM data acquired from the Late Classic Maya site of Las Cuevas in western Belize in a case study for exploring the application of immersive VR to experiential research on sound and acoustics. This site is the locale of successful ongoing research of the past that utilizes and acquires geospatial data at varying granularities (Kosakowsky et al. 2013; Galeazzi, Moyes, and Aldenderfer 2014).

Here, I Implement best practices in a consistent approach for modeling sound within archaeological spaces in order to develop a novel method for producing an immersive and accurate representation of sites of archaeological significance. The knowledge gained will also contribute to the digital preservation of historical places, their surroundings, and function. Virtual reality (VR) software and hardware are the primary means to incorporate representative data derived from and terrestrial Light Detection and Ranging (LiDAR) technology.

The primary goal here is to create and utilize a virtual reconstruction of Las Cuevas and the surrounding landscape. A virtual reconstruction or spatial analysis may be valuable in understanding the sonic experience of archaeological landscapes (Mlekuz 2004; Till 2014; Skeates 2017; Primeau and Witt 2018; Goodwin and Richards-Rissetto 2020)

The determination and testing of the tools and techniques necessary for the virtual reconstruction of the ancient Maya landscape at Las Cuevas, a ritual cave site, provided the foundation for this study. Las Cuevas was the place of intensive ritual use during the Late Classic period (Moyes 2012). Like many cave sites in this region, Las Cuevas is well preserved and unchanged significantly over the centuries. Focusing on acoustics, one question for my investigation, how can one determine if the acoustics of this cave were important to the rituals that occurred within by the ancient Maya people.

Caves play a significant role in Mesoamerican cultures (Moyes 2020). They are associated with the underworld and are considered to be a location of potent supernatural power. A digital reconstruction of Las Cuevas may appear to run counter to some phenomenological and experiential approaches because of their analytical and objective nature (Brück 2005). In other words, can one better understand a person's pre-conscious experience of space in the past through a reactive VR experience in the present? I hope to answer this question.

Due to recent advances in HDSM, archaeologists increasingly produce dense quantities of precision geospatial data through an increasingly more complex 3D digital ecosystem. The application of methods and techniques that make up this 3D digital ecosystem offer a new path forward for enhancing experiences of artifacts, landscapes, and the past in general by allowing for rich and immersive multi-sensory engagement (Di Franco et al. 2015). To better understand the pre-conscious experience of people, virtual reconstruction offers a useful means to represent and analyze the spatial attributes that enhance the user experience. This is also an opportunity for interpreting how ancient people engaged with the world. Understanding an individual's pre-conscious experience is relevant to 'naturalized phenomenology', a particular school of thought within the field of phenomenology that draws upon cognitive science (Yoshimi 2016). The affinity of naturalized phenomenology with the field of cognitive science potentially creates a beneficial connection between humanistic and scientific approaches to understanding past people and their environments.

VR reconstructions have potential applications beyond the disciplines they emerge from. For example, psychologists explore the utilization of sound and VR technology (Pettey et al. 2010; Garner 2018: Kern and Ellermeier 2020; Pettey et al. 2010). VR reconstructions provide a more immersive experience when the contribution of spatial acoustics to one's pre-conscious experience are considered. The effects of spatial attributes like acoustics are relevant to more than just the sonic experience of a space or place. While modern listeners may not be spiritually affected by a virtual reconstruction, data collected can help us better understand how sound and acoustics affect the enactive experience of space. The paramount research question of this experiment is, how do sound and acoustics within a virtual reconstruction of an archaeological site influence preconscious experience of the site? I hope that by investigating the effects of sound on a present-day audience within a particular space will help in elucidating how sound affected the people who once inhabited these archaeological landscapes. The study of sound at an archaeological site is an interdisciplinary approach that requires interactions across various disciplines (Till 2014 pg. 299).

Capturing the acoustics and sounds within a space enables the production of reconstructions of that are grounded in archaeological data (Till 2014 pg. 299). Sound and space regardless of definition are phenomenologically interconnected because sound is inherently spatial. Sound does not exist without its propagation in space (Eisenberg 2015 pg. 193). Sound creates space as much as space creates sound. Feld (2005) argues that place and sensory experience, especially hearing, are reciprocal. As one senses a place, one's senses are placed, and as places make senses, senses make place (Feld 2005 pg. 178). The multisensory nature of perception suggests that place should be conceived of in multisensory terms, yet to date work on sense of place have been dominated by ocularcentrism. I am not arguing for an exclusive focus on the auditory. There is evidence in neuroscience for interconnections and interactions between the various sensory areas of the brain, making it difficult to say something is purely visual or purely auditory. We must not consider sensory modalities in isolation, especially when discussing their relation to space. Vision often dominates our sensory perception of the world around us (Shams et al. 2000). However, Shams et al. (2000) demonstrate that sound can affect how one perceives visual stimuli leading to a distinctive visual illusion. This suggests that vision can be altered by other sensory modalities and vice versa. The research I conducted as part of my dissertation involved the creation of a VR representation of Las Cuevas derived from the data sets of Dr. Holley Moyes, as well as recorded audio. The final product was featured as an experiment with human subjects that attempted to provide a greater understanding of how spatial attributes contribute to pre-conscious experience due to the controlled nature of the VR representations. Spatial attributes adjusted within the reconstruction clarify how they contribute to the experiential journey by the user. Results of the experiment clarified how spatial attributes are relevant to sound and how acoustics contribute to and shape enactive experience.

Theoretical Framework for Dissertation

My research aimed to explore the role of spatial attributes related to sound and acoustics to better understand pre-conscious experience of archaeological landscapes through virtual reconstructions. I also asked the following additional research questions: (1) Does the contemporary experience of people within a virtual reconstruction help us understand the experience of past people as well? And (2) How does sound and acoustics shape these experiences? The representation of knowledge in archaeology, in particular representations derived from geospatial data is very important whether it is the peopling of an entire continent (Crabtree et al. 2021) or the sensory experience of urban activity (Baumanova 2020). Spatial data, especially spatial derived from archaeological contexts, are a key part of experiential focused research that has applications across anthropology (Anemone and Conroy 2018; Wrobel, Biggs, and Hair 2019).

Archaeology is at times characterized by a positivist focus on distanced objectivity (Thomas 2008). The reconstructions produced by archaeologists contribute to this but often only engage with a limited number of senses. Therefore, published archaeological media downplay certain senses that are used to gather information. Regardless of the effect, these representations are desirable for archaeological knowledge production (Moser 2012). Means of representation work in combination with description to explain the past. Media brings objects, places, and people together, but they also affect how we can immerse and engage with these very things. There are sensorial qualities to material things that resist easy description, aspects that are ignored by ocularcentric media (Witmore 2006). Therefore, my dissertation applies archaeological data to understand the attributes of spaces that contribute to the pre-conscious experience of those spaces. My approach emphasizes the sounds and acoustic properties of these spaces. Sounds generated by musical instruments for example, shape how people engage with and perceive material culture as sound evokes the physical properties and attributes of the object that produced it (Downey 2002). In a similar fashion, sound occurring within a particular space such as an archaeological landscape can be influenced by the spatial attributes of that space (Primeau and Witt 2018; Goodwin and Richards-Rissetto 2020).

Social values attributed to sound involve complex worldviews that were significant to societies and people in the past (Díaz-Andreu et al. 2017). I attempted to represent the past with an inclusive view of sound, but to accomplish this, the development of an acoustemology was necessary. Acoustemology is concerned with the ways of knowing which sound is the cornerstone to making sense of the world and achieving an experiential truth (Feld 2005). Acoustemology theorizes sound as a means of knowing by investigating into what is known and how things become known through sound. It differs from acoustics because it deals with sound as both social and material, rather than just material. Sound and listening are investigated as knowing-with and knowing-through what is heard (Feld 2015 pg. 12). But how do we approach acoustemology of past cultures? In other words, how do we understand the social and material influences on a sensory experience that differs from our own? Geoffroy-Schwinden (2018) believes that digital approaches offer the means to does this.

Acoustemology is important to understand cultures in the past because a sound-based framework can reveal new details about the past, particularly in caves (Moyes 2012; Moyes et al. 2017: Moyes and Montgomery 2019). Rather than try to think the same as people in the past, or develop an understanding of their systems of meaning, it is better to develop a shared familiarity with the sensorial affordances of encounters within specific spaces and with specific objects and people (Lash 2020 pg. 131). Experiencing and knowing place through the senses proceeds through a complex interplay of sensory modalities. Sound and space regardless of definition are phenomenologically interconnected because sound is always in motion and is inherently spatial (Eisenberg 2015 pg. 193). Sound does not exist with its propagation in space. Sound creates space as much as space creates sound. Most sound studies today deal with space in some way (Eisenberg 2015 pg. 194). To achieve a more humanistic understanding of the past, it is becoming apparent that archaeologists should supplement these methods by adding phenomenological descriptions of sites. The application of phenomenology in archaeology has primarily been employed as a critique of Cartesian positivism and a hermeneutic tool to assist in the analysis of ancient material culture (Brück 2005). Phenomenology has the potential to help in the Identification of archaeological patterns and relationships upon the landscape.

Virtual Reality (VR) And Its Significance to the Dissertation.

Due to decreasing size and costs, acoustic recording equipment can now be brought into the field to better understand the acoustic characteristics of a place, map out spatial qualities of the sound, and capture impulse responses for analysis. Impulse responses can assess what acoustic effects must be present and noticeable at a site or feature (Till 2014 pg. 294). Impulse responses are limited if the site is not fully intact and simulations and models have many assumptions built into their interpretations (Valenzuela et al. 2020 pg. 5). A consideration of sound enables us to construct a multisensory view of the past (Murphy et al. 2017). Sound plays an important role in conveying information and creating engaging and immersive multimedia experiences. At the same time, it is important to note that objective analysis of acoustics can only tell researchers so much about what a place may have sounded like. Nonetheless, a virtual reality system enhances the sensory experience by creating a dynamic interactive space with the appropriate audiovisuals. Virtual reality modeling enables multi-sensory immersive experiences (Till 2014 pg. 294). Immersive visualizations of archaeological sites currently assist in interpretation and improving our understanding of the complex spatial relationship between features at an archaeological site (Lercari and Busacca 2020).

I created a VR experience that is compatible with multiple VR headset options, including the Oculus or Vive line of headsets. VR environments do more than just copy or imitate as they act as a source of knowledge for the object being represented (Gillings 2005). By creating a richer sand more sensorially aware environment, VR enhances user engagement (Tringham and Danis 2020 pg. 68). Digital technology offers a means of evaluating and generating propositions about how people experienced the world around them in the past.

Immersive VR offers the possibilities to reconstruct and manipulate archaeological material or phenomenon that can no longer be seen, making it an appealing tool for learning about objects and processes. Unlike videos which offer a fixed perspective and no movement control. VR provides the user with agency. They have the freedom to move where they want and when they want through the virtual environment. In addition, it offers a sense of presence and an immersive experience. The immersion and interactive of VR enhances the sense of presence in users (Peterson et al. 2022). In addition, a high sense of immersions leads to large situational interest and greater engagement. Immersion is simply the state of mind characterized by being fully engaged in an environment that provides continuous sensory stimuli and experience (Witmer and Singer 1998). Immersion relates to presence, which is the experience of being in one place while being physically situated in another. Presence, immersion, and learning often go together (Witmer and Singer 1998). However, this learning is only achievable if physical and virtual interfaces are multisensorial and intuitive (Tost and Economou 2009 pg. 161). Virtual environments created using game engine platforms like Unity3D include simulation of bodily movement, lighting, and engagement with the virtual environment (Opitz 2017 pg. 1208). In addition, these virtual reconstructions can link diverse datasets together into a singular environment (Rua and Alvito 2011 pg. 3297). New geospatial technology in combination with existing spatial data improves the efficiency of both while also aiding in the digital documentation of archaeological features (Lercari, Campiani, and Stuardo 2018). This allows for the analysis of space on a human level and scale. While there is subjectivity present in how a reconstruction is made, multiple scenarios can be effectively tested within a VR environment. Virtual environments need not only be visually realistic but also interactive with active human presence. It is important that audio-visual content be a key feature of any digital reconstruction as it provides a sense of presence necessary for creating a believable embodied VR experience (Arrighi et al 2021 pg. 2).

Opitz (2017) simulates what is visible to an individual as they walk through the virtual environment. These walk-throughs are recorded and analyzed for visual saliency based on attention directed at specific areas in each scene. By utilizing principles of perceptual cues and the importance of 3D shape to attention and recognition, the archaeological interest continues in experiential aspects of the past with the recognition that our individual experiences are not representative of a universal experience (Opitz 2016 pg. 1222). Valenzuela et al (2020) argue that listening tests may prove useful in getting a subjective evaluation of sound stimuli and that listening tests are effective for how individual's perceive spaces and how their perception can affect actions. Understanding soundscape psychology will help us understand the actions and experiences of past individuals (Valenzuela et al 2020).

Ancient Maya Cave Research

This dissertation focuses on the ancient Maya cave site of Las Cuevas, Belize. Caves, hills, and mountains are major features of the Maya landscape that are the loci of ritual activities (Vogt and Stuart 2005 pg. 155) and fit into cosmological and ritual concepts that are crucial to understanding Maya religious practices. Caves and mountains are long incorporated into Mesoamerican iconography (Stone 2010 pg. 52). The earliest representation of a cave is found at the Olmec site of San Lorenzo during the Early Preclassic period in which a cave is depicted as a niche sculpted into an altar.

Image. 1: The entrance chamber of Las Cuevas.

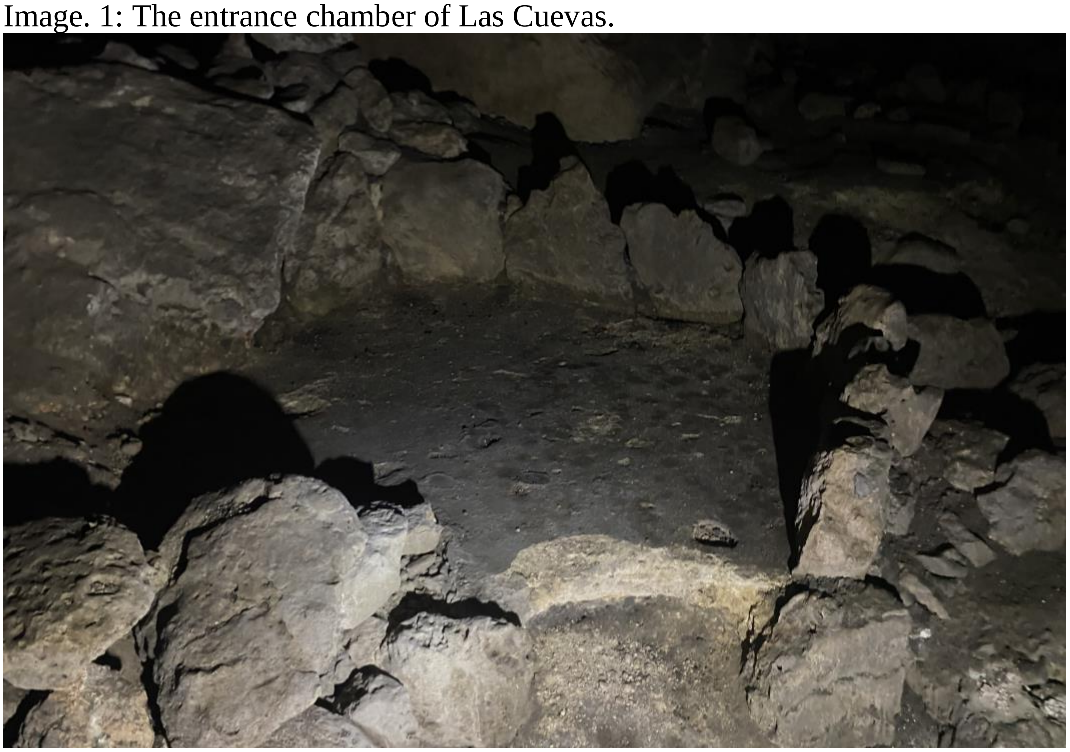


Fig. 2: Architectural features in the entrance chamber of Las Cuevas.

Most of Mesoamerica is karstic, containing limestone caves and rock shelters. The usage of these caves and rock shelters by people is well documented by archaeological, ethnohistoric, and ethnographic evidence (Moyes and Brady 2012b pg. 151). A greater understanding of the importance of caves is gained by comprehending Mesoamerican cosmology and thought. For the cultures of Mesoamerica caves, like the earth they are found in, are animate and populated with spirits and deities. Caves themselves play a major role in Mesoamerican creation myths. There is also an association with the first maize being found in caves, as well as the belief that rain emerges from caves (Bassie-Sweet 1996 pg. 10-11). Which explains their importance to water and fertility rites. This is also evident in the fact that various rain deities such as the Maya Chac and Central Mexican Tlaloc who are believed to inhabit caves (Moyes and Brady 2012) .

Caves are an excellent source for archaeological research primarily due to their primarily ritual use and excellent material preservation (Moyes and Brady 2012). Caves also provide many practical materials such as soils and minerals for pigments and the production of pottery (Stone 2010 pg. 92). Caves also contain bodies of water such as cenotes and dripping water from ceilings. This would have made sense in Mesoamerican cosmology as the world is surrounded by a body of primordial water. Since caves go deep underground, they could reach this source of primordial water. The water in caves makes them a source of rain and storms by proxy, and this ties into the notion that rain gods like Chac and Tlaloc inhabited caves (Stone 2010; Moyes and Brady 2012). Caves' association with water also gives them an association with fertility as well, as well as due to the womb-like nature of caves. This extends to agricultural fertility which explains the connection between caves and maize in Mesoamerican origin myths. For this reason, agricultural tools and implements for processing maize such as manos and metates are often found in caves (Palka 2014 pg. 165) .

Ethnohistoric, ethnographic and archaeological evidence offers important insights into understanding the importance of caves to the ancient Maya (McNatt 1996 pg. 81). The Maya thought caves were an entrance to the underworld known as Xibalba, a watery place populated by various deities representing death, disease, and other ills. "By their very structure, caves in the limestone formations of Maya country are passageways between the visible world of the earth's surface and the interior of mountains and the nether regions of the Underworld. In this borderline position, caves are prime examples of the boundary between the natural and the supernatural, between the human and the supernatural domains of the Maya cosmos." (Vogt and Stuart 2005 pg. 179). However, as noted earlier caves are also seen as source of positive forces such as clouds, rain, lightning making them connected to fertility, and life. Caves were not inanimate but living manifestations of spiritual power.

Maya Worldview and Cosmology

The ancient Maya cosmos conforms to the shamanistic model described by Mircea Eliade (1964). This world is ordered according to upper, middle, and the underworld (Morton 2018 pg. 27). The middle is inhabited by humans while the upper and underworld are inhabited by supernatural beings. "The Maya understood the world as a flat source oriented to the four cardinal directions" (Christie 2003 pg. 292). The four sides of the world orient to four cardinal directions, and the corners marked in the inter-cardinal directions. Above and below is a supernatural underworld. A thirteen layered upper world, and a lower nine-tiered world in the underworld filled with rot inhabited by the 13 lords who rule over death and disease. This model of the world was conceptualized and constructed in local geography such as mountains and caves. This cosmological model is also seen in Classic Mayan iconography, site layout, orientation of buildings and ethnohistoric sources (Christie 2003 pg. 292)

As stated above, the Maya viewed the world as quadrilateral with a mountain at each cardinal point. These mountains were where the sky and earth met, meaning the sun, moon, and stars rose and set from them. The mountains themselves were the homes of the ancestors and deities associated with lightning, rain, and wind. These mountains and the supernatural forces within were accessed through caves marked by a ceiba tree (Bassie-Sweet 1996). Contemporary Maya people see a connection between people and communities to the earth through caves and mountains (Vogt and Stuart 2005 pg. 156). This is evident in the ancient Maya ceremonial centers which housed mountain-pyramids and cave-temples. Evidence suggests that mountains and the pyramids that represented them served as residences of the ancestors. Funerary pyramids constructed in the Classic Period that hold the remains of ancestors reflect this relationship. (Vogt and Stuart 2005 pg. 157). Caves themselves are often seen as analogous to houses, or containers for beings (Stone 2010 pg. 81). This explains the connection between caves and temple superstructures. Temples were houses for the gods, and there is a shared quality in the dark, spaces that both temples and caves contain. This world model is further constructed by the Maya when they build their communities, houses, and ritual spaces (Ashmore 2004). It creates an ordered and safe space for people that is separate from the chaotic and the wild. The quadrilateral models are evident in both ancient and contemporary Maya sources (Bassie-Sweet 1996). Which suggests an amount of continuity between past and present cultures.

For the Maya, the earth itself is a square with a defined center (Bassie-Sweet 1996 pg. 21). The following description is summarized from Bassie-Sweet (1996 pg. 21–24): This quadrilateral world is oriented to the four cardinal directions. Each side was assigned a color: red/east, white/north, black/west, and yellow/south. A mythological mountain was found in each of these horizon areas. The cave found at this mountain gave access to the mountain and the supernatural as well as the sea beyond the mountains, and the underworld beyond that. Communities, temples, pyramids, houses, altars, and ritual spaces all recreate the center, sides, and corners of the quadrilateral world (Bassie-Sweet 1996 pg. 24). Natural caves found near communities were often seen as representative of the horizon caves found within the mythological mountains. Modern Maya communities are known to define their borders through four sacred mountains or caves. These cosmological views are also evident in the construction and layout of ancient Maya settlements. "Site planning was often shaped by cosmological principles, such as the three-fold layering of the universe and the fivefold cardinal directions, representing the sky (north), earth (south), sunrise and sunset (east and west), and the axis mundi (center). Ball courts were often placed at central points along north-south axes in site layouts. Application of such cosmological principles reveals that the ideological dimension often complemented environmental and economic factors in shaping site layout and planning" (Sharer and Traxler 2006 pg. 704). While the cave is a means to access the underworld, the two are separate (Bassie-Sweet 1996 pg. 52). The caves' main purpose was to access the primordial sea upon which the world floated as well as the deities and supernatural forces that inhabited this space. Caves also represented the center point of many Mesoamerican communities. A central mountain was believed to be located at the center, ideally one that had water emitting from it. These centrally located caves served as a sacred center for the community and the mythological location of their origin (Moyes and Brady 2012). While existing in opposition, caves and mountains are also seen singularly (Stone 2010 pg. 77). Rain gods for example are connected to both mountains and caves. The central Mexican rain god Tlaloc is believed to live in a cave inside a mountain as well as the Maya god Chac. Iconographic depictions of the rain deity Chac often show him in a cave or cenote. Because many caves in the Maya region contain water they were thought of as the source of surface water. It was also believed rain, mist, clouds, thunder, and lightning all originated in caves (Bassie-Sweet 1996 pg. 10). This is why water is a boundary between the earth and the underworld (Bassie-Sweet 1996 pg. 19).

Caves are also associated with water and fertility (Moyes and Brady 2012). Many indigenous people in Mesoamerica believe that water originates in caves. This is because clouds often appear to rest on mountains, even appearing at times to emerge from the mouth of caves. Procreation is also associated with caves as many cultures in Mesoamerica believe that humans were fashioned from corn and water found in caves (Bassie-Sweet 1996 pg. 11). Humans were believed to first emerge from caves. Cave deities associated with corn, rain, lightning, thunder, and wind were believed to reside in caves. These cave deities were protective and guarded the community from outside sources that might harm it. In addition to various deities, a prevalent belief among Maya is that ancestors reside in sacred caves near the community (Bassie-Sweet 1996 pg. 156). While multiple caves may contain ancestors, often only one senior cave is where the most important ancestors reside.

Rituals within Caves

The natural landscape was important to ancient Mesoamerican religious thought and activity. For this reason, it is no surprise that caves served as a ritual setting for the Maya and providing a space for performance (Moyes 2019 pg. 313). Caves functioned as places for important rituals, though they eventually became spaces in which societal elites conducted political rituals to achieve legitimacy (Moyes and Brady 2012). Supernatural experiences through heightened or altered state of consciousness appear in many parts of the Maya region (Bassie-Sweet 1996 pg. 181). Caves are an ideal location for this as they impact the ritual specialist physically and psychologically. Whether that be from the extreme darkness, or the physical exertion required to move through the cave.

Several different deities are connected to caves making them ideal places for religious rites. The ancient Maya associated the underworld with caves (Moyes 2012 pg. 99). This is emblematic in the ancient Maya glyph for caves which contains skull, bone, or a detached eye against a darkened field suggesting death and the underworld. This iconography is further associated with bat wings further emphasizing the connection between the cave and the underworld. Depictions of caves and the underworld in Maya art present on ceramics and monuments typically show the spaces inhabited by supernatural beings (Morton 2018 pg. 38). These inhabitants of the underworld are usually engaging in dance along with musicians and acts of sacrifice further emphasizing caves as spaces for ritual.

Caves are one of the most important ritual landscapes for the Maya. Ethnographic literature makes it clear that caves, ruins, and boulders were viewed as the homes of the earth lords and other supernatural entities (Palka 2014 pg. 153). Caves were locations that Maya people on pilgrimages could carry out ceremonies and communicate with their ancestors (Palka 2014 pg. 170). The pilgrimage function is made more evident by the lack of habitation in or near caves. Public ceremonies would have been held at the entrance of the cave while more private affairs would be held deeper in the narrow passages. Indigenous people in the Maya region still engage in pilgrimages to ritual caves (Palka 2014 pg. 159) offering a means of better understanding Maya religious practice in the past. The Tzotzil Maya believe that caves are a source of great wealth and resources (Palka 2014 pg. 155) but also dangerous as the earth lords can capture people and force them to work. The Ch'ol Maya in Chiapas believe caves contain human souls and the essence of the ancestors. Good and bad forces in caves can take one's soul if caution is not heeded. The Lacandon people only venture into caves for rituals as they fear caves as the realm of the deity Kisin who can bring earthquakes and disease (Palka 2014 pg. 157).

Archaeological evidence includes a wide array of ritual offerings ranging from pottery and bone artifacts to more perishable items like maize and incense (McNatt 1996 pg. 85) Large amounts of primarily broken pottery are often found dumped into caves as a form of offerings (McNatt 1996 pg. 86). These "dumps" functioned as part of religious ceremonies and rituals. Especially renewal ceremonies at the end of calendrical cycles. Artifacts and religious architecture such as altars, and shrines also occur in caves with human remains occasionally present (Morton 2018 pg. 43). Caves were used for worship of rain and earth gods which leads to a wide quantity of incense burners (Morton 2018).

For rituals, a wide array of construction also occurred in caves, as the Maya engaged in extensive modification of the ritual environment (McNatt 1996 pg. 91). Narrowed passages, sealed chambers, as well as terraces, and platforms all served distinct purposes at the time of use. Cave architecture is important to understanding ritual performance in Mesoamerica. Architecture served several purposes ranging from performance platforms, to means of separating performers from their audiences, channel movement, create focal points, force change body posture, or block views (Moyes 2012 pg. 95) Cave architecture ranges from informal laid down cobbles and boulders to more labor-intensive chinked masonry (Moyes 2019 pg. 319). Local material is often employed opportunistically, for example speleothems like stalactites are incorporated into constructions. Plaster or mud mortar is used to hold constructions together. These constructions provide a space for ritual performance. Sight lines are enhanced or obstructed, and movement is blocked or channeled. Walls may be used to enclose spaces or force one to change posture or body position to move past them.

Las Cuevas

Cave research in Belize has increased steadily. Between 1983 and 1995 the number of recorded cave sites in Belize increased from 86 to 198 and projects are constantly discovering new ones. As early as 1884, references appear in publications to ceramics recovered from a cave in Belize (McNatt 1996 pg. 82). Most publications referencing caves in this time period from 1894-1930 were by Thomas Gann, a British medical officer with an interest in the ancient Maya and their use of caves.

Located in western Belize, Las Cuevas is an excellent example of a public performance space. The first visit to Las Cuevas (then known as Awe Caves) was undertaken by Alexander Hamilton Anderson a British civil servant in 1938. The British Museum eventually excavated Las Cuevas in 1957 with the assistance of Anderson. Las Cuevas consists of a small to medium surface site with a large cave system below it (Moyes 2012 pg. 96). It is found in the Chiquibul Forest Reserve in Belize. It has been investigated by the Las Cuevas Archaeological Reconnaissance project since 2011 (Moyes 2019 pg. 322). The surface site consists of 26 structures ranging from a temple, to plazas, to a ball court. Directly below the eastern most building in Plaza A sits the entrance of the cave. The entrance chamber to this cave is massive with constructed and modified platforms, stairs, and terrace. The space is comparable in size and grandeur to many outdoor plazas. In addition to the entrance, parts of the cave's interior are modified with walls and partitions to restrict space. The heavily modified entrance chamber is 108 m in length, 40 m in width, and 17m in height. There are a variety of architectural features such as terraces, walls, stairs, and platforms most of which have a thick layer of plaster (Moyes 2019 pg. 327). In the center of the chamber a cenote with an underground river divides the chamber. Retaining walls and stairways that descend into the river line the sinkhole. Seventy-five individual platforms surround the cenote in an "amphitheater-style" configuration.

It is clear the cave entrance was intended as a public performance space while the tunnel system was reserved for those willing to brave the spiritual dangers within and offer a worthy sacrifice (Moyes 2012 pg. 107). The various walls and blockages reduce access and force a change in body posture in order to move through the tunnel system. These restrictions separate the cave entrance from the deeper parts of the cave, representing a separation of the earth from the underworld. Las Cuevas was a public performance space analogous to plazas at surface sites, but with the additional association of the natural landscape. "Cave construction recreated cosmic space, reified cosmological principles, and enhanced the embodied experience for the ancient users" (Moyes 2012 pg. 107). Consideration of human experience and embodiment allows for one to view architecture as dynamic structures that shaped people's journey through the tunnel system and therefore the underworld.

Farther back in the entrance chamber the light faded away leading to a walled entrance to the tunnel system. Beyond this first wall is a tunnel system 335 meters in length and consisting of 10 rooms and passages. The end of the tunnel results leads to a window overlooking the floor of the entrance chamber. The acoustics are impressive from this window, and one can easily be heard by people on the platforms below. "Las Cuevas makes the strongest statement of ancient Maya cosmological principles and creates the most salient backdrop for ritual performance of any known cave site in the Maya Lowlands." (Moyes 2019 pg. 328)

The mountain, cave, water complex is evident at the site of Las Cuevas. Here a temple sits directly atop a large natural cave entrance containing a cenote. This cave entrance is a venue for public performance that created a strong cosmological statement (Moyes and Brady 2012B pg. 156).

Ancient Maya Sounds

Mesoamerica is full of caves and tunnels (Bruchez 2007 pg. 47). These underground spaces are home to a wide variety of sounds from ground movement, water, wind, and wildlife. By understanding the noises that occur within these environments, a better comprehension of how people respond to these aural phenomena is possible. Inhabitants of Mesoamerica understand and appreciate sounds, claiming that the underground speaks. This may be why caves, and mountains may have been seen as the residence of gods of rain, wind, thunder, lightning, clouds, and corns.

Sounds are likely one of many reasons humans visit underground spaces as sacred spaces (Bruchez 2007 pg. 50). The variety of sounds occurring underground can lead to socially and spiritually rewarding events. Reverberations are often enhanced in underground spaces that can help hear otherwise inaudible sounds.

People in Mesoamerica revere underground sounds associating them with the voices of the ancestors, animals, music, or an otherwise invisible presence (Bruchez 2007 pg. 53). There is an association in Mesoamerica between the earth and powerful sounds whether that be a jaguar, bird, crocodile, or macaw. Underworld beings are often accompanied by musicians seen as making the clamor. For example, a crocodilian creature appears as one of the musicians in the Bonampak murals (Bruchez 2007 pg. 55).

Katz (2019 pg. 118) argues that music was central to ancient Maya ceremonial activities and identifies a strong connection between music and wind as responsible for the role of music in mythology. Music not only controls the wind but the Maya believed wind brought music into the terrestrial world. Musical instruments are associated with the wind, and none are more apparent than the conch shell, which has a form evocative of wind. This is evident in the use of a conch shell as a symbolic representation of breath and wind. In addition, the conch shell is often depicted alongside entities associated with the wind such as the plumed serpent, a creature of wind. Like the conch shell the flute is also associated with wind, and both are thought to be the voice of the ancestors. There is a link between music, breath, wind, and ancestors. The Maya believed the ancestors could not eat solid food and consumed offerings carried by the wind such as incense and music (Katz 2019 pg. 120). The Maize God is one such example of the connection between wind and music (Katz 2019 pg. 121). If wind is present, the Maize God dances in the same way that cornfields sway and rustle in the wind. This is why the Maize God is often depicted dancing with rattles. When the wind is present, dancing and music are present. The Maya thought music could summon the wind as evidenced in Late Classic vessels depicting a scene of the Wind God being captured (Katz 2019 pg. 122). The Rain

God along with several warriors are depicted capturing a young noble representing the Wind God. This ritual capture of the Wind God by the Rain God represents the fact that rain needs wind in order to be blown over the fields (Katz 2019 pg. 123). This ties into caves because caves were seen as a source of wind, mist, clouds, and rain (Katz 2019 pg. 124). Music and wind are connected as the Maya believed wind created music and brought it into the terrestrial world, and once here music could summon the rain generating winds (Katz 2019 pg. 129).

Overview of Chapters

The second chapter of this dissertation focuses on the theoretical approach of this dissertation. It begins with an introduction to how this dissertation takes a digital approach to phenomenology to expand upon the perceived limitations of phenomenology. An overview of postprocessual archaeology is provided. Postprocessual archaeology showed an interest in noneconomic phenomena and challenged the earlier positivist approaches of processual archaeology. Postproccesualists such as Tilley (1994) possessed an even greater humanist approach and began to look at human experience and how people engage with the world around them. This is related to the origins of both landscape archaeology and philosophical phenomenology. Landscape archaeology and interest in human experience is best understood through its adherent grounding in philosophical phenomenology. Philosophical phenomenology is primarily connected with Continental European philosophers Husserl (1997), Merleau-Ponty (2005), and Heidegger (2008), with the origins found in the work for Frantz Brentano (Thomas 2006 pg. 44). Brentano (2015) presented the idea of ‘intentionality,’ which manifests as connected individual mental events. Objects make their appearance within these thoughts as ‘presentations’ and serve as the fundamental building blocks of consciousness. Brentano inspired his student Edmund Husserl who first introduced the concept of ‘phenomenological reduction’ (Husserl 1980). Husserl’s interest in consciousness and experience would influence the phenomenological archaeology of postprocessualists like Tilley (1994). However, phenomenological archaeology is affected even more so by the older traditions of chorography and antiquarianism (Gillings 2011 pg. 54). These earlier traditions are the roots of the interest of archaeological phenomenology in direct engagement and experience of the landscape. Tilley (1994) wrote one of the more influential pieces of phenomenological archaeology. In his work “Phenomenology of Landscape”, Tilley (1994) challenges traditional views of the landscape and argues that his own contemporary experiences of landscape allow the connection with the experiences of people in the past. Perhaps not surprisingly, phenomenological approaches in archaeology have faced several major critiques mainly focused on the perceived lack of evidential rigor and subjective nature of the research (Johnson 2012). Due to these critiques, archaeologists have recently begun to utilize an ‘archaeology of the senses’ (Hamilakis 2014). While proponents claim otherwise, it is in many ways a rehashing of familiar phenomenological principles. Despite this criticism, phenomenology aids in the identification of archaeological and relationships across the landscape (Brück 2005 pg. 64-65). Phenomenologists such as Tilley (1994), Bender (1995), Cumings (2004), and Hamilton (2006) have primarily focused on British prehistory with a clear visual focus. This ‘ocularcentrism’ emerges because the microscope, telescope, and camera all play major roles in the development of empirical scientific observation (Thomas 2012). Reality is defined as what can be viewed with fidelity at the expense of other senses. In order to expand beyond the visual, I expand upon the usage of digital approaches to enhance the three-dimensional properties of artifacts and evoke embodied, multisensorial engagement with them in chapter 3.

Building upon this, the third chapter develops the methodological focus and begins with an overview of the early history of computational and digital methodologies in archaeology as well as the significance of their impact upon the discipline. Since their first appearance in the 1960's and 1970's, these methods enabled more complicated manipulation and utilization of data for a variety of purposes. Next, the chapter reviews digital technologies utilized to reconstruct past sensory experience: (1) Geographic Information Systems (GIS) is examined and considered as a means of understanding sensory experience in the past; (2) 3D mapping technology is reviewed and considered as a means for understanding past sensory experience; and (3) Virtual Reality (VR) and Augmented Reality (AR) are considered as viable options. Based on this overview, VR is determined to be the ideal candidate for a better understanding of past sensory experience. Several case studies for VR are reviewed in-depth to better explain both technological upsides as well as limitations. Game engines like Unreal Engine offer a means of creating an interactive virtual environment that is explored using VR technology with head mounted displays such as the HTC VIVE. VR in combination with game engines enable multisensory engagement with 3D reconstructions of archaeological artifacts and landscapes. It is appeals to users because archaeological material or phenomena that is not easily accessible or no longer in existence can be interacted with. In particular, the use of sound convey information and creates an engaging as well as immersive multimedia experiences. The illusion of a space with the appropriate acoustics is produced in VR. In addition to sound, the ability to move through the virtual landscape helps in evaluating how people experienced this past world. To test how VR helps in understanding sensory experience in the past, it is combined with qualitative experiments and quantitative testing utilizing students as participants. The use and value of sound in a virtual environment is discussed.

The next portion of Chapter 3 reviews the creation of a VR environment representing the ancient Maya cave site of Las Cuevas, Belize. The process of going from the raw point cloud data collected at the site to a solid mesh useable in Unreal Engine is explained. Additional steps in the creation process are also elaborated on, such as the development of environmental features such as water and rain, and various sound effects found throughout the environment including bats and dripping water. A detailed summary of the steps required to create the VR environment is provided. The survey of VR participants is reviewed and described with a synopsis of the questions asked and how a t-test was applied to test the results. In addition to a survey, player locations were logged and the average minimum and mean distance from landmarks by the players were was analyzed. A memory test was created and explained in regard to its function and purpose.

The chapter 5 documents the results of the experiment. An overview of the results from the memory test is provided. These results are discussed in detail and a summary of answers to demographic questions asked of participants before the experiment are presented. A visualization is provided for each question to help the reader understand the results of demographic questions. Next, the survey questions post-experiment are reviewed and graphically presented. T-test results of the post-experiment survey questions are reported. As t-test of player movement is reviewed based on the mean and minimum distance from a number of landmarks in the VR environment. Finally, k-means clustering of player movement is provided.

The sixth and concluding chapter looks towards the future and examines how to build upon and improve the experiment, e.g., improving data collection through the implementation of eye-tracking. Also, a consideration of sensory experiences beyond sight and sound and how to utilize WAVEs and CAVEs in this experiment is provided. Finally, the complexities of working with the selected computer software, Unreal Engine 5, is dissected with an emphasis on future developments on how to effectively use the software and accompanying computer hardware.

Dissertation Chapter 2: Theory

Digital Approaches to Phenomenology

The field of archaeological theory encompasses a diverse array of approaches and perspectives that shed light on the study of the past. Landscape archaeology is one such approach with a complex and evolving history that spans centuries. The ability to create detailed models of various interpretations of the past that can be altered to fit various hypothetical scenarios is one of several advantages computer technology offers. Yet, the dichotomy between computer-based approaches and phenomenological ones has not been bridged (Eve 2012 pg. 582). Archaeologists attempting to better understand past perception and social behavior have generally fallen into two distinct camps: (1) Those who utilize computer technology such as GIS; and (2) Those who rely on phenomenological approaches when conducting research on the landscape itself.

Archaeological phenomenology has often been criticized for being highly subjective and lacking a clear methodology (Johnson 2012). The use of contemporary embodied responses to the landscape is thought to be highly subjective and reflective of the “I” of the present-day observer rather than the “they” of past populations (Johnson, 2012). Phenomenological archaeology lacks the ability to run experiments with empirical results that can be repeated and studied by other archaeologists.

Computational approaches remove the viewpoint of embodiment within a space. Yet, at the same time, these approaches allow for nearly infinite combinations of variables to use to explore possible scenarios of what the past may have been like. However, with digital approaches, no account of social ties, connections people have with the world around them, or features of the world that exist outside of sensory inputs are visible.

Various methods have been utilized by phenomenological writers to illustrate the relationships they identified. Many used photographs, while others made videos and sound recordings. Photographs, videos, and sound recordings may be less abstract than traditional cartography, but they are also selected and edited representations of the landscape (Brück 2005 pg. 51) now used to overcome the abstract perspective of 2D maps and enable researchers to understand orientation, movement, and intervisibility within an environment. Multiple experiences of a place are enabled since the user can navigate the environment they choose. Similarly, GIS is employed to investigate experience (Primeau and Witt 2018). GIS analyzes patterns of intervisibility with viewsheds and considers a myriad of factors, including ground cover, terrain, vegetation, and soil. Phenomenological approaches, however, are typically descriptive in nature. Data that demonstrate regularities in sensory effects are not often available. However, GIS enables comparison of data from many sites. This means relationships that are identified are unlikely to be the result of chance. Yet GIS and VRM are still objectivist, Cartesian models of space. They run counter to phenomenological approaches because of their analytical and objective nature. People's experience of landscape is not solely determined by the material. Regardless, Brück (2005) argues GIS and VR cannot be easily dismissed because of their value in identifying symbolic patterns on the landscape. The use of GIS and other technology can supply the evidential base and critical rigor necessary to counter critiques of phenomenological approaches (Johnson 2012 pg. 280).

This chapter: (1) Explores the origins and development of landscape archaeology, as well as its connection to phenomenology, a philosophical framework that delves into human experience and consciousness; and (2) Reviews the critiques and debates surrounding these approaches, highlighting their significance in reshaping our understanding of the archaeological landscape.

Postprocessual Archaeology

An alternative to earlier processual approaches in archaeology first emerged in the 1970s, and by 1985 Ian Hodder labeled it, "postprocessual archaeology" (Trigger 2008 pg. 444). The first influence on the establishment of an alternative to the processual approach was social anthropology inspired by Marxism that emerged in the 1960s in France that aimed to combined Marxism and structuralism. This period saw a broader reaction against positivism and behaviorism in the humanities and social sciences and was recognized as postmodernism (Trigger 2008 pg. 446). Postmodernists embraced the subjective nature of knowledge and extreme relativism/idealism. They denied the possibility of objective knowledge. Postmodern idealism rejected physical constraints on human behavior (Trigger 2008 pg. 447). A single, objective version of people was rejected. There were multiple truths depending on perspective. Their subjectivist viewpoint meant that no two people saw the world the same. Postmodernism flourished in archaeology though extreme subjectivism and opposition. The lack of grand narratives made it hard to gain insight into social systems (Trigger 2008 pg. 448). As an overt movement, postprocessual archaeology began in Britain and influenced by the work of Ian Hodder. Hodder hoped to apply theoretical insights from French Marxist anthropology to study material culture (Trigger 2008 pg. 450).

One major component of early postprocessual archaeology was the unique attention given to noneconomic phenomena such as religion and belief. Postprocessual archaeologists generally challenged positivist approaches to archaeological data (Trigger 2008 pg. 452). Some postprocessual archaeologists such as Christopher Tilley (1994) and Julian Thomas (2001) argued that positivism focuses on what can be sensed, tested, and predicated. As a result, positivism produced knowledge that facilitated exploitation by the elite. Hodder (1985) believed the main purpose of archaeology was to provide individuals with the means to develop their own interpretations of the past. Relativist ideas along with opposition to elitism and a monopoly on knowledge by archaeologists associated with more dominant countries/institutions in the United States and Western Europe were key. Christopher Tilley (1994) introduced the third wave of postprocessual archaeology known as intuitive, constructivist, or humanist archaeology (Trigger 2008 pg. 473). This approach sees biologically grounded humans overlaid with experience and is primarily based on phenomenology that repudiates separation between observer and observed. Humans are not subjects manipulating objects but creatures who reciprocally interact with the world. For humanist archaeologists like Tilley, human thought and behavior was always interpreted as relating to artifacts. By gaining an understanding of how humans engage with artifacts, buildings, and the natural environment, a better understanding of general beliefs, feelings, and attitudes of past people could be reached (Trigger 2008 pg. 473).

Origins of Landscape Archaeology

The origins of landscape archaeology are varied and complicated (Thomas 2012 pg. 167). Early influences include 17th century antiquaries' examination of boundaries, enclosures, and burial mounds that were clearly pre-modern. Later 19th century work treated the landscape as an analytical frame or unit of analysis. The landscape was seen as a palimpsest of material culture that was uncovered through fieldwork. Unfortunately this early landscape archaeology was rather limited in its approaches to understanding the lives of humans in these places under research (Johnson 2012) .

The 1990s see the emergence of "postprocessual landscape archaeology" with distinct views on human perception, experiencing, and meaning. Some archaeologists like Christopher Tilley and Julian Thomas consider their methodology an alternative to more empirical approaches to landscapes, while others such as Stuart Eve (2012) see themselves as complementary to the ways of investigating the landscape.

Landscape archaeology holds a major impact on the research of prehistoric monuments in Europe and Britain since aerial photograph of Stonehenge was first done in the early 20th century (Capper 1907). The interest in studies of mobility and intervisibility in and around monuments has increased because such patterns of movement may have had importance to past peoples. It has become more and more clear that monumental architecture is dependent on the landscape it is situated in (Thomas 2012).

The term landscape has multiple meanings contributing to difficulty In understanding It. It can refer to topography and landforms, or the land people inhabit. The landscape can be an object, experience, or representation. Nonetheless, archaeologists have identified the landscape as offering a framework for connecting different types of information and different aspects of human activity (Thomas 2012). More typically, archaeologist are referring to a landscape that is objectified. While past and present can never fully meet, experiential archaeology of landscape can function as a means of generating new conversations and perspectives. “Our engagement with the material traces of the past does not give us access to past experiences, but it provides a basis for understanding how far they may have been unlike our own” (Johnson 2012 pg. 181). It is important to keep in mind that the background against what we interpret ancient artifacts and features is largely a modern one, made up of contemporary skills, practices, and experiences. Our experience of a place or artifact is valuable as more than just that product or outcome of ancient social life. It represents a key component of the landscape. In order to understand the significance of an artifact or feature, we must place it into a context as complete as possible. To understand postprocessual landscape archaeology, the origins of philosophical phenomenology that many of adherents such as Tilley (1994) draw from need strong consideration.

Origins of Philosophical Phenomenology

The origins of phenomenology lie in the philosophical study of human experience and consciousness (Johnson 2012 pg. 272). Johnson suggests that human experience is not simple nor commonsense. Phenomenology is primarily associated with Continental European philosophers such as Heidegger (2008), Husserl (1997), and Merleau-Ponty (2005) and an understanding of human experience that is (1) material rather than textual; and (2) mediated through the body not language with an emphasis that the senses and everyday activity combine to move beyond mind-body dualism. Phenomenology emphasis the body and is an interrogation of lived experience. The wider social practices that influence experience of landscape in the past were of interest to phenomenological archaeologists like Christopher Tilley (1994) and Vicki Cummings (2004). A product of this is documented by the form, appearance, and location of monuments. There is an emphasis in phenomenological archaeology on going beyond traditional approaches to archaeological landscapes such as plan and aerial views (Thomas 2012). Phenomenologists view traditional depictions of the landscape in aerial and plan views as limited and point out that people in the past would not have seen these environments in the same way. There is instead an emphasis on, and the description of, that subjective experience (Johnson 2012 pg. 274).

Phenomenology owes its origins to the pioneering work of Frantz Brentano (Thomas 2006 pg. 44). Brentano laid the foundation in the early 20th century for what he referred to as ‘descriptive psychology,’ which focused on exploring the significance and content of cognitive acts. The central argument of Brentano (2015) was mental phenomena, unlike their physical counterparts, always possess a directedness or intentionality towards something. To grapple with the intrinsic directed nature of conscious activity, Brentano (2015) introduced the concept of ‘intentionality,’ which manifests as interconnected individual mental events. Objects make their appearance within these thoughts as ‘presentations’ and serve as the fundamental building blocks of consciousness. The presentations within our mental activity become comprehensible through intentionality.

Brentano’s concept of intentionality (2015) had a profound influence on Edmund Husserl, who sought to develop his own brand of phenomenology as a form of descriptive psychology (Beyer 2022). In his quest to delve into the intricacies of perception, Husserl (1980) aimed to identify the fundamental structures that underpin consciousness. According to Beyer (2022), Husserl maintained that consciousness is invariably oriented towards some object, establishing intentionality as a cornerstone of his philosophical inquiry.

For Husserl, consciousness perpetually engages with something, whether that something is a tangible physical object or an abstract concept like a mathematical formula (Husserl 2007, Thomas 2006 pg. 45). This, he believed, rendered intentionality as the starting point for understanding the intricate relationship between individuals and the world they inhabit. The phenomena that Husserl’s phenomenology aimed to study were the very things that appeared within consciousness itself. By directing consciousness towards objects, individuals were granted a gateway to something from the external world. In many ways, Husserl (2001) was concerned with the notion of intuition, the profound insight that emerges when we recognize that something is inherently correct or true. This recognition, in his view, was facilitated by the intentional nature of consciousness.

The overarching goal of Husserl (2001) was giving unbiased description of human experience as it is, leading him to devise a method he termed ‘phenomenological reduction.’ This method sought to unveil the universal essences that underlie human perception (Husserl 2001). It entailed the act of ‘bracketing’ or temporarily setting aside the presuppositions that invariably surround any experience, revealing the core essence of consciousness. These presuppositions that needed to be suspended were collectively referred to as the ‘natural attitude,’ which signifies the ordinary, everyday perspective from which we approach the world.

Husserl coined the term ‘hyle’ to describe the raw material of human experience, a chaotic and formless substrate that resists comprehension in its native state (Beyer 2022). Humans, he argued, bring order and intelligibility to this raw material by directing their attention to objects, thereby rendering them comprehensible and incorporating them into their conscious experience. This transformation occurs because the human mind possesses a series of ideal objects known as ‘noema,’ which become imbued with meaning through lived experience and structure our perception of the world.

The ultimate aspiration of Husserl (1980) was to cultivate an 'eidetic' science of consciousness rather than a factual one. This ‘eidetic’ science, akin to disciplines like geometry and mathematics, prioritizes the exploration of abstract essences over empirical observations (Husserl 2001). According to Husserl (2001) in such a scientific framework, truth is elucidated through logic and reason rather than deductive or inductive analysis. Husserl envisioned phenomenology as precisely this type of ‘eidetic’ science, one that delves into the essence of consciousness itself. Husserl perceived that phenomenology would have methodological priority over other sciences, with a strong opposition to naturalism and orientation of phenomenology towards the natural sciences.

Naturalized Phenomenology

Yoshimi (2016) notes that despite Husserl’s opposition to naturalism, phenomenologists often utilize empirical sources. The author offers a direction that naturalized phenomenology may take in which phenomenology is merely one approach utilized amongst many. He notes that phenomenology is unique able to offer a rich source of theoretical data to draw upon. At its most fundamental level, phenomenology can provide useful data for the researcher to explain. For example, asking subjects to report on what they perceive in an experiment. Phenomenology can also influence the design of experiments by providing concepts and distinctions. It also provides a coherent theoretical framework for better understanding empirical results. Rather than considering results individually they are placed together into an account of lived experience

Moyes (2023) notes subjective observations could be utilized for orienting archaeological research as well as offering hypothetical data to be analyzed. She specifically notes the study of sound in the archaeological record as an area of research in which modern observations would be relevant to the development of hypotheses. Such an approach she argues would fit well with naturalized phenomenology. By studying subjective human experience empirically, both archaeology and phenomenology can be expanded upon. Caves are argued by Moyes (2023) to be a prime subject for study because of their exotic nature and the unique phenomenological experiences within them. A naturalized approach would better connect the ethnographic present to the archaeological past while simultaneously mitigating issues inherent to subjectivity. While philosophical phenomenology had a major influence on postprocessual landscape archaeology, its influences run deeper and older than that.

.

Moyes et al. (2017) showed how phenomenology can be expanded to help address archaeological questions and questions about human thought. The effects of low-light conditions and whether it leads to cognitive changes were studied in an examination of 104 participants. Participants were evenly split with some in a light room and some in a darkened room. Each participant was asked to answer a series of questions about supernatural thinking and the attribution of anomalous events to the supernatural. Results were subtle but suggested that a dark room lead to a higher-than-average rating in supernatural thinking. This study helps legitimize utilization of phenomenology in archaeology and the viability of reconstructions in bridging the gap between past and present. Evaluating shared human experience through rigorous methods will provide a way for grounded phenomenological approaches in archaeology.

Naturalized phenomenology allows for the first-person experience of the individual while still making an effort to validate those experiences scientifically. The experiment run as part of this dissertation is intended to be in the vein of naturalized phenomenology. Rather than rely on people's biases. Peoples responses are pooled together to get a better sense of what people experience in VR.

Origins of Phenomenological Archaeology

Phenomenological archaeology draws upon earlier traditions of chorography (Gillings 2011 pg. 54). "This (chorography) emphasized the uniqueness and character of specific regions, placed a premium on perambulation and direct engagement and evoked and expressed a strong sense of place (and pride in place)" (Gillings 2011 pg. 57). Chorography is not a word often used in archaeological research. It comes from ancient Greek: graphe (a written description) and khoros (a country, district, or region) (Gillings 2011 pg. 58). It falls somewhere between topography and geography. However, unlike geography there is less emphasis on quantitative and technical surveying and mapping. The main goal of chorography was to capture the likeness of the landscape through words. It was meant to evoke more than just the spatial navigation through the places mentioned, but rather highlight important locations, historical facts, as well as local folklore and gossip. However, the emergence of natural philosophy and its adherentsov like Francis Bacon lead to a shift away from chorography towards a more empirical antiquarianism. Regardless this shared grounding chorography links landscape phenomenology to early antiquarians (Peterson 2003).

The 18th century antiquarian William Stukeley is known for his study of prehistoric sites around Avebury in England. He was one of the first to examine and study these monuments. Peterson (2003) discusses Stukeley's thinking from his examination of the Stukeley collected work (Peterson 2003 pg. 394). Peterson (2003) argues that there are parallels between Stukeley's early thinking and the phenomenological work of Tilley (1994). Both approaches show an emphasis on embodied experience of the landscape that differs from traditional cartesian representations of space (Peterson 2003 pg. 395). The field recordings of Stukeley (1740) at Avebury are primarily views of the monuments from his perspective in combination with field notes containing compass bearings to provide a three-dimensional view of the monuments (Peterson 2003 pg. 395). The illustrations of Stukeley in 1740 suggest a different understanding of the landscape than typically abstracted plan views. He regards the monuments within their context of the broader landscape, a view more in common with recent phenomenological approaches to landscapes (Peterson 2003 pg. 397). Stukeley makes use of Cartesian data to create representations of the monuments that are not just focused on a two-dimensional plan view (Peterson 2003 pg. 398). Stukeley's approach is close to the concerns of phenomenology in overcoming the modern, distanced view of the world. Like Tilley, Stukeley goes beyond the two-dimensional plan view to record encounters with a monument within the broader landscape (Peterson 2003 pg. 399, Stukeley 1740).

Phenomenological approaches to the landscape are popular in archaeology and are primarily focused on the prehistory of Britain and Europe (Johnson 2012 pg. 269). The application of archaeology is most often employed as a critique of Cartesian positivism and a hermeneutic tool to assist in analysis of ancient material culture. Some see it as having limited impact outside of Britain (Johnson 2012). Outside of Britain phenomenology is one of many means with which to engage human subjectivity in the landscape (Johnson 2012 pg. 275). Questions of experience are of concern to archaeologists across a wide range of theoretical positions (Brück 2005 pg. 45). A more generalized interest in human experience has developed in archaeology since the emergence of postprocessual approaches in the late 20th century. This particularly British approach has been criticized on epistemological grounds and evidential criteria due to a lack of adherence to empirical evaluation (Fleming 1999). Critics of phenomenology have also challenged how effectively descriptions of human experience particular to the modern Western world can be applied to ancient societies and cultures (Brück 2005 pg. 45).

Archaeological phenomenology emerged out of the postprocessual critique in the 1980s and 1990s that encouraged explorations of human subjectivity, symbolism, and meaning (Johnson 2012 pg. 269). Postprocessual archaeology rejected a positivist view of science with no separation between theory and data (Johnson 2010). Data is both influenced by theory and data is seen through a “cloud” of theory. The opposition between material and ideal is also rejected by post-processualism. Interest in practice, thoughts, and ideas do not arise in the abstract but in practical activities such as movement through the landscape. Thoughts and values of the past need to be viewed with the same interest as artifacts and sites. Individuals in the past were not passive followers but active in their understanding and manipulation of rulers. Early post-processualism derived from structuralist approaches encouraged material culture to be read like a text (Hodder 1985), and like a text, material culture meant different things to different people, with hidden meanings often found within. As a result, there cannot be a one-size fits all approach or singular conclusion on material culture. The meaning of the “text” is outside of the creator’s control. Phenomenology arose as an alternative to these textual metaphors (Johnson 2012 pg. 270). Johnson (2012) identified three background influences on the early phenomenological approaches to the landscape:

1. The subjective construction of the landscape as seen in interdisciplinary approaches such as human geography (Johnson 2012 pg. 27). Earlier attempts to view the landscape in an objective manner were neither neutral or objective. They arose from the historical context of the Renaissance and early capitalism that abstracted and commodified conceptions of space.
2. The nature of archaeological data itself. Many of the initial adherents of phenomenological approaches to the landscape were British post-processualists like Chris Tilley and Julian Thomas who took for granted a local landscape dense in archaeological features. These landscapes were numerous and easily accessible. This encouraged repeated visitation and

experienced these sites in different seasons and weather. The density of features also made walking among them and their description both effortless and appealing.

3. The explicit political agenda in archaeological studies of the landscape. There are multiple often conflicting views of the landscape both past and present. Many argue that archaeologists must engage with these.

Tilley's Phenomenology of Landscape

Perhaps one of the more influential pieces of phenomenological archaeology is the study of Tilley (1994). In his "Phenomenology of Landscape," Tilly delves into the concept that the world we live in is not merely static material, but a realm imbued with profound meaning. This perspective serves to contextualize the landscape within a broader framework. However, it is important to note that Tilley's work faced criticism from various viewpoints. Some critiques adopt an empirical stance, while others accuse Tilley of stretching the available evidence beyond its limits (Johnson 2012).

Tilley's foundational assumption is that his own experience of the contemporary landscape serves as a bridge to connect with the experiences of people in the past. Other scholars raise concerns about the tendency of phenomenological approaches to present the human body as an anonymous and universal entity (Brück 2005). Brück (2005) and others argue that an overemphasis on the lives of individuals from the past often neglects the absence of universal experiences among diverse historical populations.

In sum, these critiques challenge conventional understandings of the landscape as a neutral entity. Tilly (1994) argues that modern visualizations of landscapes have been shaped by capitalist economics, reducing the landscape to a quantifiable and marketable resource. In response, he calls upon archaeologists to reengage with the qualitative dimensions of landscapes by investigating how social and cultural elements become embedded in specific places (Tilley 1994 pg. 17).

Tilley (1994) asserts that the full experience of a place cannot be captured by abstract two-dimensional representations of the landscape. Place, he contends, is inherently three-dimensional and sensorial, a dimension often overlooked in traditional landscape descriptions. Space, according to Tilley, is always situated and contextual, which implies that our understanding of a space is shaped by our movements within it (Tilley 1994 pg. 27).

In conclusion, Tilley's "Phenomenology of Landscape" challenges conventional perceptions of the landscape, emphasizing its rich meanings and the contextual, three-dimensional aspects often disregarded previously. While his work remains controversial and not without criticism, it prompts a reevaluation of how we perceive and interact with the landscapes around us as archaeologists consider the intricate interplay of history, culture, and space.

Critiques of Phenomenology

Phenomenology in archaeology remains a controversial and contested area of theory (Johnson 2012 pg. 276). The first main issue is evidential. Many of the claims and observations phenomenologists such as Tilley make could reference a whole range of features on the landscape. Ambiguous claims with multiple meanings make it difficult to disprove the conclusions that follow. While a demand for evidential rigor is valid, it is unwarranted to claim that phenomenological approaches necessitate the rejection of evidential criteria. Eve (2012) and others have shown that approaches like GIS can help provide the evidential rigor phenomenology is often accused of lacking. Phenomenology is also sometimes criticized for assuming an unity to human experience (Brück 2005). All individuals do not experience the landscape in the same manner. In archaeology, the individual tends to be the solitary able-bodied male (Johnson 2012 pg. 277). It is debatable whether our experience of walking through the landscape in the present allows one to fully grasp the experience of people in the past. This assumes a psychic human unity, not an anthropologically grounded understanding of human experiences and being culturally situated. Edmonds 92006) argued that there is an underlying cultural romanticism to Phenomenology, resulting in the recreation of many romantic assumptions: the solitary protagonist; disembodied accounts separate from everyday life; the authority attributed to direct bodily experience; and the critique of modernity as inauthentic, poetic/artistic influences. All are artifacts of Romantic and neo-Romantic tradition (Brück 2005). Phenomenology tends to engage with artistic and performative approaches to the landscape that are more subjective. These are inspiring and great for community engagement. However, if not done properly they risk being self-indulgent, and lacking in depth/rigor as demonstrated by Tilley's (1994) lack of clear defensible evidence of his claims. Unfortunately, this only adds to the critique of evidential rigor. Nonetheless, archaeologists are all phenomenologists to an extent according to Johnson (2012 pg. 279). Few would deny that subjectivity does not play a role in understanding the landscape.

A key question to phenomenology and related approaches is whether contemporary engagement and/or modeling of the landscape can approximate the experience of ancient people. Such assumptions are found in the approach of Tilley (1994). Tilley (1994) argues that the physical human body and landscape places similar limits on people in both the past and present. According to Tilly (1944), the experience of modern people will not differ significantly from that of past people. Unfortunately, it is unclear how walking the landscape as Tilley recommends actually contributes to our understanding of the past (Brück 2005 pg. 54).

Perhaps the harshest critiques of phenomenological approaches in archaeology have come from Fleming (1999, 2005, 2006). Fleming (1999) initially focuses on Chapters three and four of Tilley's 1944 Phenomenology of Landscape which examines the megalithic landscape of western and south-eastern Wales. Here Tilley identifies relationships between the megalithic tombs and the surrounding landscape features such as hills and outcroppings. Fleming (1999) believes this to be promising but finds this treatment by Tilly of field data unsatisfactory because it fails to increase the understanding of the Welsh Neolithic landscape. Fleming (1999) argues the megaliths in south-west Wales are not a robust dataset to study because of the dense distribution of heterogeneous features. This is not indicative of a common mindset or belief among their builders. Site destruction is problematic and lead to a sampling problem. The surviving sites are located on the less valuable land in which small quarries or outcrops meant the tombs were not dismantled for stone. Fleming (1999) also thinks that Tilley (1994) provided adequate alternative interpretations to his own. Fleming (1999) thinks a range of factors shape the location of megalithic tombs. They could have been built to command a very localized area just as much as they could overlook a much larger space.

Flemings (2005) expands upon this critique to encompass the work of Vicki Cummings (Cummings and Whittle 2004). He coins the term “Tilley-Cummings approach” (Fleming 2005) to define the problematic methods he reviews. Focusing on Tilley and Cummings’ work in south-eastern Wales, Fleming (2005) argues their claims lack rigor due to the tomb’s state of preservation that contributes to determining the exact orientation of the tombs ambiguous. Tilley (1994) and Cummings and Whittle (2004) also argue about the visibility of certain features from these sites. Flemings (2005) finds their claims of significance on any site arbitrary if not outright overambitious. There is also no successful connection made with ethnographically derived insights by Cummings and Whittle (2004). Fleming (2005) focuses on the strength of arguments put forth by Tilley (1994) and Cummings (2005). Fleming (2005) criticizes Cummings (2005) for the frequent use of the word ‘seems’ in her approach to monument-landscape relationships. Targets are identified frequently but without further explanation. Fleming thinks the use of the adjectives “possible and probable” evidence means the evidence seems extensive to the authors, contra Fleming who finds this evidence to be non-existent (Fleming 2005 pg 923). The approach of Fleming (2005) allows something meaningful to be said about the site relative to the surrounding landscape. Claiming that monuments have a significant connection to a nearby location based on perceived distance means the same could be said for any feature of the neighboring landscape (Fleming 2005 pg. 924). According to Fleming (2005), it is an oversimplification to claim that an elevated site has phenomenological significance when much of the surrounding landscape is visible from it (Fleming 2005 pg. 927). In conclusion, this criticism by Fleming attempts to cast traditional archaeological fieldwork as Cartesian and sterile in comparison to experiential phenomenological approaches (Fleming 2005 pg. 932) and that fieldwork should be supported by observation, rational positivism, and healthy skepticism.

In his final article, Fleming (2006, pg. 276) expands his critique beyond Tilley and Cummings to what he calls “post-processual landscape archaeology”, a paradigm that has received little critical evaluation in his opinion. Fleming (2206) reasons that post-processualists have challenged traditional means of verifications to the point that they feel they can say whatever they like. He posits that these approaches were meant to address the lack of people in studies of landscape archaeology (Fleming 2006 pg. 276). Fleming (2006) thinks past people are not more absent in traditional landscape archaeology than in any other sub-discipline of archaeology and makes the claim that Cartesian frameworks are unavoidable and are not lacking in consideration of the mindsets of past people. Even Tilley worked with a camcorder and two-dimensional images (Tilley, 1994; Fleming 2006 pg. 278). Post-processual theorists argue that traditional approaches to the landscape ignore the inhabitants of those landscapes, and that these traditional approaches can be supplanted by experiential forms of fieldwork and writing. However, Fleming argues that field archaeologists must think critically and an instinct for objective weighing of evidence (Fleming 2006 pg. 279). Phenomenology is the subject of numerous critical reviews(Brück 2005; Fleming 1995, 2005, 2006), but remains a useful means of conducting archaeological research (Brück 2005).

Based on these heavy critiques, archaeologists have increasingly turned to an ‘archaeology of the senses’ (Hamilakis 2013). The strongest proponent of this approach being Yannis Hamilakis (2013). Hamilakis (2013) claims to offer a new paradigm to help rethink archaeological questions and methodological procedures. He aims to challenge modernist archaeology which he argues is ocularcentric by offering a multi-sensorial archaeology that recognizes vision as only one of several senses that operate together in a synaesthetic manner. Despite the similarities to phenomenological archaeology, Hamilakis (2013) is critical of phenomenological approaches. Primarily he focuses on the work of Tilley (1994) for several reasons. Hamilakis (2013) argues that Tilley (1994) considers the sensory experience of past people without examining his own sensory experiences as a modern Western archaeologist. In addition he believes that Tilley is criticized for not making a break with modern Western ontology defined by rigid subject-object division. Overall, he sees no attempt to break away from the Cartesian lineage of modernist archaeology.

Despite distancing himself from phenomenological archaeology, Hamilakis (2013) and other adherents of sensory archaeology seem to take an approach that is remarkedly similar to that of phenomenological archaeology. One such sensory archaeology study by López and Skeates (2022) demonstrates this. López and Skeates (2022) aim to understand to understand the multisensory aspects of caves and surrounding landscapes in the Valencia region of Spain. They argue that peoples engagement with caves can be better understood through understanding the sensorial influence of caves and the surrounding landscape on human movement, experience, and perception. They utilize their own first-hand experiences of walking across the landscape leading to two caves that were believed to function in some ways as ritual spaces. Their conclusion is that they expanded upon existing archaeological means of observation and documentation, by the addition of sensory data that offered improved interpretations of ritual experiences in the past. Despite claims to the contrary the approaches used by sensory archaeology studies are reminiscent of the approaches used in the earlier phenomenological archaeology. Perhaps for this reason it is best to consider sensory archaeology simply a rehashing of the same ideas brought up by phenomenologists like Tilley (1994) with minor changes. Unlike Tilley (1994), Hamilakis (2013) sees the validity of VR and other technologies to better understand the experience of people in the past. He argues that digital devices can expand and extend our bodies sensorial capabilities. Digital devices can produce sensorial experiences and enable experimentation that help in understanding both the present and past. Though he notes that VR applications needed to be implemented within existing archaeological processes. Regardless it is best not to dismiss phenomenological approaches in their entirety as it still has much to offer.

The Importance of Phenomenology

Phenomenology aids in the identification of archaeological patterns and relationships upon the landscape (Brück 2005 pg. 64-65). However, what those patterns and relationships mean is indeterminate. Nonetheless, phenomenology emboldens new methods of inquiry regarding the social and political implications of space, place, and landscapes. Phenomenology deconstructs dualistic thinking remaining in archaeology from post-Enlightenment rationalism (Brück 2005 pg. 65) and reassesses the relationship between people and artifacts, as well as other dichotomies such nature and culture, self and other, subject and object. It is vital to recognize that artifacts, buildings, and monuments are not passive but active, affecting the viewer and help make humans who they are. This allows for improved engagement with the archaeological record by constructing a dialogue between archaeologists and what they study.

Past and present can never fully meet, but experiential archaeology of landscape can function as a means of generating new conversations. "Our engagement with the material traces of the past does not give us access to past experiences, but it provides a basis for understanding how far they may be unlike our own" (Thomas 2012 pg. 181). It is important to keep in mind that the background against which we interpret ancient artifacts and features is largely a modern one, made up of contemporary skills, practices, and experiences. Our experience of a place or artifact is valuable because that object is more than just a product or outcome of ancient social life. The object represents a key component of that pattern of human interaction with the landscape. To understand the significance of the artifact or object under study, we must place that particular artifact or feature into as much of the surrounding landscape as possible.

Phenomenology helps identify archaeological patterns and relationships within the landscape (Brück 2005). However, what those patterns and relationships actually mean remains difficult to decipher because of the incomplete nature of the archaeological record. Still, new methods of inquiry regarding the social and political implications of space, place, and landscapes have emerged. Methods such as GIS viewsheds, and least cost-paths as well as digital reconstructions of past places and landscapes using the latest gaming engines. It is vital to recognize that artifacts, buildings, and monuments are not passive but actively affect us and make us who we are. This allows for better engagement with the archaeological record by constructing a dialogue between archaeologists and what they study.

Exploring Subject, Object, and Archaeology: A Multisensory Journey Through Time and Space

Archaeology, the science of uncovering and interpreting the remnants of the past, has long been shaped by the dominant mode of perception in the modern Western world—vision (Thomas 2008). A journey through the annals of history, monuments, and landscapes is often a visually driven one, leaving the other senses such as hearing largely neglected. In archaeology, there exists a fascinating interplay between the subject and the object, the observer and the observed, and the past and the present. Archaeologists, despite their multisensory excavation processes, often present the past in overwhelmingly ocular-centric terms, whether that be plan and section drawings or aerial photographs). This dichotomy between subject and object perpetuates a division between the senses, further prioritizing only visual representation. This unfortunately leads us into the heart of ocular-centrism in archaeology, where modernist approaches have entrenched autonomous and disembodied vision as the norm (Thomas 2008). In this chapter, I explore the digital realm as a potential bridge between the senses and archaeological representation. Digital methods, such as computational imaging and 3D printing, offer a way to transcend the limitations of 2D representation and static visual rendering. These methodologies can improve the visualization of the three-dimensional and multisensory aspects of artifacts, opening up new avenues for engaging with the past. This course of research takes us further into the realm of virtual reality (VR) and immersive experiences, where these technologies enable more engaging interactions with material culture. Virtual Reality and 3D printing allow for a richer exploration of artifacts, enhancing sensorial experiences and public engagement (Di Franco et al 2015). While not perfect, these technologies expand our sensory capabilities and encourage curiosity about the material past. Digital technologies provide an informative interaction between computer modeling and a phenomenological approach in archaeology. The divide between those who rely on technology like Geographic Information Systems (GIS) and those who conduct phenomenological research of the landscape itself becomes narrower. Each approach has merits and limitations, and here I consider how they can complement each other. Archaeology ultimately leads us to reflect on the importance of representing landscapes in nontraditional ways. Landscapes engage all our senses but their conventional representations often fall short in conveying a multifaceted, holistic experience. New technologies and alternative methods offer opportunities for richer, multisensory engagement with the past, expanding the status quo of visual-centric narratives.

Subject, Object, and Archaeology

Tilly (1994), Cummings (2004), Barbara Bender (1995), and Sue Hamilton (2006) mostly focusing on British prehistory, have taken similar approaches grounded in phenomenological archaeology. These studies emphasize the present embodied experience of archaeologists as a means of analyzing the past experiences of monuments and landscapes. Many researchers have expanded beyond Tilley's primarily visual focus (Brezina 2013; Đorđević and Novković 2019; Eve 2012; Kopij and Pilch 2019; Primeau and Witt 2018; Ortoleva 2021) Smell, touch, hearing, and other senses all play a role in how the landscape is experienced. These are absent in ocular centrism in studies in the modern Western world which explains the Cartesian 'gaze" evident in many archaeological maps and plans (Brück 2005 pg. 50). Contemporary western conceptions of landscape are grounded within a wider modern worldview that focuses on the following: (1) Separation between subject and object; and (2) Separation between culture and nature (Thomas 2021 pg. 170). There is a connection between the subject-object relationship and ocularcentrism in the modern Western world that is also evident in archaeology (Thomas 2008). Ocularcentrism favors the visual over all other senses, a result of the emergence of the microscope, telescope, and cameras playing a major role in the development of empirical scientific observation (Thomas 2012). Reality was defined as something in the arts and sciences that could be represented with fidelity and objectivity. This was achieved principally through visual means such as graphs, maps, photographs, and verbal descriptions. This way of seeing the world became the approved way of truly seeing the world and extracting information from it (Thomas 2008). The world could be divided into self-contained pieces of reality that are separated from their surrounding context. “This way of seeing, in which the mind acquires information through an ocular apparatus, amounts to the dominant mode of visuality in the modern world, in which the objective constructions of realist representation have become linked to the knowing subject of rationalist philosophy” (Thomas 2008 pg. 2). What this leads to is a world where humanity is separated from the natural environment. The world becomes viewed as a set of material things that are merely resources to be examined and extracted.

Placing vision on a pedestal above all the other senses goes back to the writings of Plato and other ancient Greeks (Hamilakis 2014 pg. 32). Aristotle came up with the five senses linking them to primary elements: water (sight), air (hearing), fire (smell) and earth (touch); sight, hearing, and smell were highest ranked and considered humanizing senses (Hamilakis 2014). Early Christian and medieval thinkers saw the senses as a source of sin to be tamed. Only hearing and seeing were acceptable as senses for the experience of God. The sense of taste was considered very sinful (Hamilakis 2014 pg. 33). In the 16^{th} and 17^{th} centuries, the so-called Cartesian perspective emerged which separated the physical from the metaphysical. Descartes’s view of the senses did not go much beyond sight, which he saw as the best and brightest of the senses (Hamilakis 2014). Descartes considered a disembodied god’s eye view, not the actual sensory experience of individuals, as the most important. He though the world should be viewed from above, such as from a map or aerial photograph, as being amid everything, chaotic, and not easily understood. Perception and vision became understood in Western thought as a means of mediation between the physical and metaphysical. In other words, subject and object were viewed as separated entities. This was evident in early archaeology which viewed the past as only learned from objects that were separate and not reflective of the humans who either created or interacted with these materials An example being early aerial photography of prehistoric sites such as Stonehenge (Capper 1907). Despite the new perspective an aerial view offered there was little effort to understand more about the people who made these ancient monuments.

Vision was seen as superior because of its detached remoteness able to separate entities in ways that the other senses could not (Hamilakis 2014). Archaeology was influenced by this focus on the visual which became evident in methodology, distanced objectivity, and well-defined visualization and description. However, this had the unfortunate effect of creating a past that was not easily understood as inhabited or embodied. Despite the lack of openness to embodied experience, archaeologists deal with materials through a physical multi-sensory process of excavation (Hamilakis 2014). Objects are more materially complex than one sense can truly apprehend, yet the past is conceived of in strongly ocularcentric terms. This also reinforced the subject-object dichotomy that needed to be resolved. According to Thomas (2008), separating the subject from the object creates a world of unambiguous entities that visual perception captures like data for a computer. Separation of subject and object also creates an unnecessary separation between the senses that favors visual representation.

Ocularcentrism in Archaeology

Modernist archaeology is ocularcentric and reliant primarily on an autonomous and disembodied vision (Hamilakis 2014 pg. 73). A multi-sensorial archaeology of material culture will recognize that vision is incorporated with the other senses in a synaesthetic manner. The modern Western sensory paradigm is grounded in colonial and nationalistic desires for power and control (Hamilakis 2014 pg. 32). A desire to conquer seemingly unruly people and places is reflected in the desire to control the senses. This is evident in early archaeological studies such as studies of settlement patterns which produced representations grounded on sight and vision that were disconnected from the experiential multi-sensorial experience of reality (Parson 1972). From its beginnings, Western archaeology develops a troubling relationship with sensorial experience. This relationship with sensorial experience is grounded in visual mediums like photography (Thomas 1945).

According to Hamilakis (2014), photography enabled vision that could be separated from the viewer, and enabled the production of copies that became commodities for circulation and consumption. Photography enabled more efficient documentation, the categorizing and cataloging of artifacts and other antiquities removed from colonized regions. These objects could be efficiently commodified and “made visible” to the public and to other scientists. Even artifacts left behind in colonial regions could be “taken” or recorded via photographs back to the colonizers home country. The visible experience in photography helps produce the archaeological construction of the past and therefore the present. Archaeologists could delineate, rebuild, name and exhibit artifacts or sites at their leisure. Photography according to Hamilakis (2014) evokes monumentality, timelessness, and a place of past rather than present. A view of the world through photography was sanitized and meant to be enjoyed through autonomous vision. A multi-sensorial perception of the past was deemed off-limits to the public and often many communities surrounding artifacts or sites were kept away to prevent destruction or degradation. This is evident in the maps used by archaeologists that have their roots in colonial endeavors that identified native land as “empty” in order to claim it (Milhauser and Morehart 2016).Part of this controlled access to the artifacts was based on a desire to regulate sensorial experiences and sanitize them. Only the highest-ranking sense, vision, is allowed to interact with artifacts. The senses perceived as lesser are not allowed to interact with artifacts, without risk of contamination.

Expanding the Visual-Verbal Through the Digital

The primary impression of most archaeological objects is through the visual. Information is usually reducible to mediums that are dominated by the visual and verbal such as drawings, photographs, maps, and documents. Therefore, peer reviewed literature often downplays certain senses that are used to gather information and emphasizes the visual. This is evident in the peer-reviewed literature that use GIS to study visibility

(Murrieta-Flores and Martin 2020), compared to the relatively few that study sound (Primeau and Witt 2018). Hurcombe (2007) argued analysis of artifacts emphasize sensory perceptions such as sight, even though materials and material culture are identified as sensorial extensions to the human body which cannot be separated from it into Cartesian dualities of subject and object. "The relationship between materials and materiality is intimate and rooted in practical sensory experiences" (Hurcombe 2007 pg. 536). How we perform interactions with materials and their affordances shape the social construct. Therefore, the role of senses is a largely unrecognized feature of our ability to understand materiality in other cultures. Properties of materials are essential information that can be investigated via senses and technologies to better understand social contexts. Sensory experiences can help understand objects as individual pieces as material evidence of past concepts of materiality. By focusing on the sensory perception of objects, new meanings for them can be theorized. I agree with Hurcombe (2007) that a better sense of materials in concepts of materiality is required to better understand tangible material objects. Artifacts need engagement using as many sensory modalities as possible in order to understand them. Digital methods provide a superior platform to mobilize the senses. Digital representations do not take the place of or replace the original objects or places, but are necessary for academic research, exhibit, discussion, and the sharing of our discoveries.

Traditional archaeological methods of recording such as field notes and photography turn a three dimensional multisensory world with properties like color, texture and geometry into a flat static two dimensional space (Papadopoulos et al. 2019) though still fulfill first level documentation. The sensorially absent assemblage evokes rather than records the material world. Objects and places have material and sensorial dimensions to them that other means of documentation in archaeology do not fully capture. Rather than treat objects and places solely as images, perhaps it is advantageous to consider them as multidimensional and multisensorial. Papadopoulos et al. (2019) argue that digital methodologies such as computational imaging not only enable new means of interpreting artifacts but also enable the study of artifacts and things as multidimensional rather than mere images. They believe that utilizing these methodologies within an experiential, multi-sensorial framework enables one to challenge visual, static, and two-dimensional representations of artifacts. The study by Papadopoulos et al. (2019) exists within a larger call to action against ocularcentrism and the representation of vision as abstracted and disembodied. Ocularcentrism leads to representations of artifacts as static and two-dimensional Cartesian renderings that flatten and conventionalize. Conventional representations obfuscate the three-dimensional qualities of artifacts that enable embodied, multisensorial experience of those artifacts (Di Franco et al. 2015). Digital methods can enhance three-dimensional properties of artifacts as well as evoke embodied, multisensorial effective experience. Papadopoulos et al. (2019) advocate for digital methods as a means to enhance multi-sensorial embodied engagement with physical artifacts. The purpose is to extend the sensory abilities of the human body rather than attempt to produce a dematerialized, virtual reality.

Archaeological representations generally focus on attributes that are primarily stylistic such as form. They do not generally attempt to reflect the multi-sensory elements of the object. Eve (2018) argues that 2D and 3D representations leave out vast amounts of multi-sensory information about objects. Something is missing from replications that focus strictly on the visual. There is a propensity to focus on what things looked like, rather than how they were used and experienced (Eve 2018). Three dimensional models are limited to a screen or 3D printed material. The smells, sounds, and feel of an object are lost in 3D reconstructions. Eve (2018) considers some ways in which the multi-sensory nature of 3D digital objects might be enhanced because placing vision at the top of the sensory hierarchy leads to a loss in understanding when attempting to replicate an object digitally. Experimental archaeology and 3D printing both offer approaches to understanding the multi-sensory nature of artifacts. However, experimental archaeology is time consuming and expensive in terms of material and training. Nonetheless, in order to replicate an object from 3D digital record, multi-sensory attributes need to be documented by archaeologists. Unfortunately, visual elements are much easier to document than sound and smell. This is not helped by the ocularcentric nature of recording in archaeology. Most tools and skill-sets record nothing but the visual. Therefore, archaeologists must become re-sensualized in order to become aware and appreciative of the senses other than the visual. I assert that archaeologists can be re-sensualized by incorporating digital methodology that goes beyond the visual and engage multiple sensory modalities such hearing.

Di Giuseppantonio Di Franco et al. (2015) investigate how immersive VR environments and 3D printing enhance interaction with material cultural objects from museums and at archaeological sites. They argue that handling and manipulation of objects is vital for producing meaning in present and ancient artifacts. Few studies have investigated how these new and emerging technologies affect our interpretation of the past. The results of Di Giuseppantonio Di Franco et al. (2015) suggest that people prefer immersive 3D virtual experiences over visual non-manipulative experiences. Such 3D technologies offer a path forward for enhancing experience of artifacts and going beyond the inability to handle material things. Virtual Reality software and hardware allows for interactions that help create rich and immersive experiences despite being non-tactile. Additionally, 3D printing enables new presentations for the broader public audience. Both of these new types of presentation improve sensorial experiences and engagement with the past. Di Giuseppantonio Di Franco et al. (2015) demonstrate that a more immersive engaging experience with artifacts and it come from the ability to engage multiple sensory modalities. In order to understand material culture, we must engage with that material culture through our senses such as hearing, and not just the visual and textual. While still improving, these new technologies and their applications produce innovative engagement, increased attention, and spark curiosity about past material cultures (Tost and Economou 2009). Technological devices have multi-sensorial possibilities but in sensorial archaeology they have been primarily relegated to autonomous vision (Hamilakis 2014). Sensorial experiences are more than just chemical and neurological reactions. Memories, affects, and the body all play a role in the sensory experience. Materials and artifacts expand and extend the sensorial capabilities of our bodies. Digital devices produce sensorial experiences in present/past, but movements, memories, and performances are still required when VR applications are implemented within the entirety of the archaeological apparatus. Digital devices such as VR equipment need to be used for experience and experimentation in addition to representation.

The current orthodoxy of VR must be challenged in order to provide a new place In the discipline for it (Gillings 2005). VR-based approaches require space to develop and evolve. First, recognizing the connection between visual concordance and realism is a direct result of ocularcentric approaches that place vision at the top of the sensory hierarchy. Virtual reality is dependent on culturally specific knowledge to be comprehended, and that culturally specific knowledge is modern, Western, and ocularcentric. Rather than use VR models as objective representations of reality, it is better to employ them as constructs that can never be fully authentic. No matter how photorealistic a model looks it is not the past and never will be. Authenticity in models is a process and a relationship between people and the world rather than an attribute. Visual realism is just one aspect of a faithful reproduction. Despite the inauthenticity of VR, it is neither worthless or deceptive. VR enables new means of engagement and interpretation through process rather than details of form. Like the introduction of photography, VR imposes a particular way of seeing upon the viewer that requires culturally specific knowledge to understand. Rather than attempt to fit VR within existing frameworks, a new framework is needed for it to work most effectively in archaeology. Phenomenological approaches offer that potential framework.

Cummings (2010) study investigates how visualizations are used by archaeologists to discuss landscapes and provide a visual reference for theoretical points or case studies. A key issue identified in landscape archaeology is how the landscape is presented to the reader (Cummings 2010 pg. 285). This is especially important when attempting to understand the experience of past landscapes as experience is not easily replicated. Cummings (2010) notes an unfortunate tendency for archaeologists to treat landscapes as strictly visual phenomena, portraying them through maps, photos, and videos. Yet landscapes engage all the senses and are not strictly a visual experience. The traditional ways of representing a landscape are based on Cartesian notions of space as evidenced in aerial photography and high-resolution mapping. An increase in the use of GIS enables data to be assembled from across the landscape, making it easily manageable. However, GIS is limited in representation and characterization of landscapes. Despite innovations in 3D GIS, the landscape is often represented in a static 2D perspective from above. Virtual reality is increasing in popularity, enables new ways to experience landscapes beyond the visual, and simultaneously produces a landscape that has never actually existed. Regardless, is it important to consider innovative ways of landscape representation that offer alternative approaches to experiencing and dwelling in landscapes. These new technologies offer an alternative to traditional text-based narratives. The more experiences enabled through digital representation, the greater the chances alternative interpretations will emerge and move archaeology forward.

The use of computers greatly influences and transforms how researchers engage with the world around them (Grosman 2016 pg. 130). New means of gathering, storing, and retrieving data are now possible. In addition to novel analytical and interpretive approaches, new and emerging digital technologies indicate a paradigm shift similar in scope to the first motion picture cameras. The digital era allows for the analysis of data from different dimensions, not just the static 2D one (Grossman 2016 pg. 139). Also the nature of digital data stimulates new modes of thinking and contributes to a high-resolution, easily transported global view of archaeological research rather than a patchwork of regional views.

Origins of Computational and Digital Methods

Computational methods emerged in the late 1960's and early 70's (Chernhall 1968; Whallon 1972). Computers enabled more complex analysis and calculation of archaeological data than was possible before (Whallon 1972 pg. 30). An essential use of computers in archaeology is the handling of large quantities of data that could not be easily managed manually previously. The use of computers made data organization and visualization significantly easier (Whallon 1972 pg. 31). For example, the analysis of 8,000 textile artifacts from the Metropolitan Museum of Art allowed the analysis of individual traits and combinations of traits to determine changes in the manufacturing of Peruvian textiles as time passed (Chernhall 1968 pg. 18). Without computerized data reduction, the volume of data that required analysis could not be easily accomplished by a person. Whallon (1972) believed that the iterative nature of calculations means that computers are required. In other words, the number of times a calculation must be repeated within one set of data that sits within a larger set of data and so on. These early computer projects were all focused on the artifact level of analysis to better understand behavior in the past, or how artifact technology clusters together. However, it was noted by Chernhall (1968) that several limiting factors existed with early computer technology at the time the article was written. Though many of these are not applicable today it is still important to consider:

1. Equipment: Computers continually becoming faster, more reliable, and capable of greater processing power. However, such powerful computer equipment is not always available to scholars.
2. Form of data: When working with artifacts the researcher can order the material how he or she sees fit. Larger site level analysis requires data reduction from the observations, or a re-statement of observations into a common taxonomic scheme.
3. Training: Archaeologists are not always intimately familiar with statistical analysis, or computer programming languages.

Archaeology in this early period of the 1960's and 70's is "borrowing, experimenting, and adapting" (Whallon 1972). Existing means of simulation, spatial analysis, or other computational approaches derive from other fields rather than emerging from within archaeology. "The computer has virtually come of age in archaeology. Archaeology must now come of age in the area of computerized data analysis." (Whallon 1972 pg. 41). Even today archaeologists must still work to determine what methods and techniques are most effective for research. Especially as new technology such as Lidar (Light Detection and Ranging) and VR (Virtual Reality) evolved into innovative means to explore the past.

Survey of Methods Used to Reconstruct Past Experiences

Three major digital technologies are currently used to reconstruct past sensory experiences: (1) Geographic Information Systems (GIS); (2) 3D mapping technology; and (3) Virtual Reality and Augmented reality (VR and AR). A review of each technology is provided here followed by a consideration of the most viable technology for undertaking the requirements of this dissertation research project. The potential of VR is evaluated as a method to facilitate multi-sensory integration in the reconstruction of past experiences.

Geographic Information Systems (GIS) uses integrated computer systems to analyze landscapes and other artifacts to create a comprehensive picture of an environment. GIS also analyzes spatial patterns of movement, visibility, and sound propagation and environmental factors such as vegetation (Kosiba and Bauer 2013; Gillings 2012b; Primeau and Witt 2018; Landau 2015). Patterns identified with GIS can then be compared between sites to find regularities in sensory effects within sites (Brück 2005). For example, viewsheds can provide results and information on what can or cannot be seen between two fixed points on the landscape (Howey and Brouwer Burg 2017). Another example is the least-cost path (LCP) modeling, which determines the optimal path between two points on the landscape 36nderstandding topography and features that potentially impede movement. A phenomenological critique of GIS is that it assumes an objectivist, Cartesian model of space. Additionally, a peoples' experience of landscape is not solely determined by material culture. Also, GIS struggles to deal with imprecision and uncertainty. It is perhaps better suited to physical measurements rather than the intangible social world (Brück 2005). While I agree that GIS has these features, it would be hard for archaeologists to replace well-established GIS-based spatial methodologies that allow the integration, analysis, and visualization of vast amounts of data from different formats.

In archaeology, the ability to integrate and analyze data is fundamental for discovering spatial patterns hidden within the landscape. For this reason, Brück (2005) thinks GIS and 3D mapping cannot be dismissed because of their value in identifying symbolic patterns on the landscape. GIS can be viewed as a supplement to rather than a replacement for phenomenology. Geospatial techniques can be used to assist phenomenological approaches that emphasize the creation of space through navigation. Therefore, phenomenological approaches are grounded in observation and description of the archaeologist's experiences of places, as experience is facilitated by our universal physiology, enabling a better understanding of past peoples' experience (Primeau and Witt 2018). However, due to the static nature of GIS it was determined that it would not be the most suitable for running an experiment as part of this dissertation.

A second digital technology used to reconstruct past Is 3D mapping. A typical visualization of 3D models is in a bi-dimensional screen, supplements the abstract perspective of 2D maps, and allows researchers to understand movement, visibility, and acoustics within an environment but with all the advantages of a three-dimensional framework that better resembles the physical characteristics of a real environment. 3D mapping methodologies, such as structure-from-motion digital photogrammetry and laser scanning, effectively replicate the visual elements of an object, such as size and shape (Eve 2018). The creation of 3D models enable new means of interpreting artifacts and enable the study of artifacts and objects as multidimensional rather than mere (2D) images (Papadopoulos et al. 2019). Conventional representations such as plan and section drawings may conceal the three-dimensional qualities of artifacts that enable embodied, multisensorial experience of those artifacts. Digital methods can foreground three-dimensional properties of artifacts as well as help create an embodied, multisensorial-rich experience.

Here critics such as Thomas (2008) have charged that the emphasis of 3D mapping is ocularcentric. A 3D model in a bi-dimensional screen fails to take advantage of the complexity of the data fully. These reconstructions continue to focus strictly on the visual. There is a propensity to focus on what things looked like rather than how they were used and experienced. Similarly, 3D printed material fails to replicate the actual texture, color, and weight of the original. Though it is important to note that these shortcomings are being overcome as the technology improves. The smells, sounds, and feel of an object are lost in these 3D reconstructions. Stuart Eve (2018) argues that 2D and 3D representations leave out vast amounts of multi-sensory information about objects.

However, as with GIS, 3D mapping methodology retains its importance as an objective data set that can be used to supplement and constrain phenomenological description. 3D mapping produces objective representations that can then be subjectively observed and experienced. As much as 3D maps seemingly differ from subjective interpretation, they can be enriched by phenomenological approaches and vice versa. Neither approach fully captures the richness of artifacts, sites, and landscapes, but instead, they supplement one another in a mutually beneficial manner. Objective 3D maps would be sterile and lifeless without supplementing phenomenological approaches, and phenomenological approaches would lack the weight to their argument without supporting objective data such as 3D mapping. However, there remains the issue of incorporating sound with visuals that makes Virtual Reality an ideal methodology.

Virtual Reality (VR) and Augmented Reality (AR) are new digital technologies used to simulate and reconstruct past experiences. Virtual reality is an immersive experience using virtual objects inside a virtual environment (such as video games), while augmented reality is virtual objects inside a physical environment (like Snapchat lenses). Both techniques use virtual objects, but augmented reality is adding digital objects into a real physical environment. Virtual environments and objects can be engaged with web browser plugins such as Cortona3D, game engines like Unity3D, and viewed in stereo 3D in a CAVE (Sanders 2014). Cave Automated Virtual Environments (CAVE) are immersive VR systems that utilize several screens to produce stereo images (Knabb et al. 2014). Polarized glasses worn by the user produce a 3D stereoscopic perspective that mimics how people see in 3D in the real world. A CAVE system can display many different data types ranging from laser-scanned models to lidar point clouds.

Augmented Reality enhances a real-world environment by adding computer-generated sensory input like sound and digital models (Di Franco et al. 2015). The users perspective of reality is enhanced rather than attempting to reproduce a new reality. Augmented Reality offers a novel means of visualization, data analysis, and human engagement with material objects. This innovative means of interaction and engagement creates a rich and immersive experience. As a means of presenting the past, AR improves the sensorial experience people have with the past. These experiences are also known as mixed-reality, which exist in a continuum from reality itself to AR to VR [as a hybrid combination of virtual reality (virtual objects in a virtual world) and augmented reality (virtual objects in a physical world), where users can physically interact with virtual objects.]

The critique of mixed reality systems Is that they produce “a landscape that has never actually existed (Cummings 2010).” They often represent a person’s subjective mental interpretation of a place or object rather than an authentic, fully objective recreation. In addition, it is not yet possible to produce representations or reconstructions that offer people the same sensory experience as the real thing (Galeazzi 2018). However, VR and AR provide essential value (Gillings 2005). Rather than attempting to fit VR within existing frameworks, a new configuration is needed for this technique to work most effectively in archaeology. Their creative aspect is compelling but ways to integrate them into phenomenology and other established methods of archaeology must be explored. Like the introduction of photography, VR creates a particular way of seeing upon the viewer that requires culturally specific knowledge to understand. It is important to consider nontraditional landscape representation methods that offer new approaches to experiencing and dwelling in landscapes (Cummings 2010).

Digital technology offers the possibility of multimodal integration. VR, AR, GIS, and 3D mapping can provide immersive engagement with the past through reconstructions that engage multiple senses rather than just one. Sight and sound are important to perception (Díaz-Andreu et al. 2017), and the senses cannot be considered as separate from each other. To understand peoples’ experiences in the past, the use of digital technologies allow the integration of multiple senses into an immersive simulation. If designed and implemented appropriately, simulated immersive experiences can help comprehend how people in the past engaged with the world through their senses. A multi-sensorial experience framework expands the world of material objects and can better connect these objects to experience (Hamilakis 2014). Digital reconstructions can expand and extend our bodies’ sensorial capabilities to understand past peoples’ sensory experiences better. The use of these new technologies are one such approach as an alternative to traditional text-based narratives. The more experiences available through digital representations, the more possibility of alternative interpretations. The value of 3D models to archaeology as a whole depends on their integration with and interaction into existing methods of analysis with phenomenological descriptions. The 3D models and maps created by archaeologists can be integrated into Virtual Reality and Augmented

Reality systems with other media to create a multi-sensory experience with both sights and sounds.

Examples of Virtual and Augmented Reality Research in Archaeology

This section describes several examples showing how VR and AR systems produce rich simulations that facilitate phenomenological reconstruction. VR and AR produce immersive simulations by integrating multiple sensory modalities into a singular virtual environment. VR and AR systems also integrate multiple datasets, discoveries, and artifacts for reconstructions that account for change over time in a site. Lercari and Busacca (2020) show how VR and AR can provide reliable reconstructions of archaeological sites grounded in datasets produced with scientific rigor. This approach means that VR and AR can advance the understanding of past peoples' experiences within a space because the reconstructions are based on accurate archaeological data rather than conjecture or guesswork. These reconstructions reflect what past people in those spaces experienced and how that experience changed over time. Goodwin and colleagues (2019) illustrated how AR utilizes sound and the auditory perceptions of those sounds as a means of producing a more immersive experience of archaeological sites and landscapes that go beyond mono-modal reconstructions based solely on the visual. Goodwin and Richards-Rissetto (2023) demonstrated how VR and other digital approaches enhance our understanding of sight and sound in the past through novel approaches to data analysis, integration, visualization, and interaction. Virtual environments act as a catalyst for the interpretation of past peoples' experiences, and interactive 3D visualizations embedded with sounds of the past allow for a multi-sensory representation. Shemek et al. (2018) demonstrate how immersive VR technology enables meaningful embodied engagement with virtual reconstructions of cultural heritage that have been altered over time. They show how a multi-sensory interactive environment integrates multiple multimodal data sources within a single virtual environment for an immersive and affective experience of a past place, in this case, the Reinassance era studiolo (study) of Isabella d'Este's. Barreau et al. (2015) brings together historical documents and archaeological knowledge to produce a scale 3D model of an 18^{th}-century ship. Not only do these 3D models offer an immersive visual experience, but the authors integrate a soundscape into the reconstruction that helps to understand what life was like onboard the ship when it actually sailed the ocean.

Lercari and Busacca (2020) utilize immersive VR to create archaeological visualizations that assist in interpreting behavior and provide a better understanding of site chronology. The 3D reconstructions they produced of the Neolithic site of Çatalhöyük offer a multi-temporal look at the sequence of construction over time. These reconstructions provide visual representations of a complex archaeological record and increased appreciation of the history of buildings at Çatalhöyük. Lercari and Busacca (2020) produce archaeological visualizations that successfully reconstruct multiple building phases at the site to better understand the links between different phases of occupation. Their interactive virtual reconstructions visualize continuity and change patterns evident in the archaeological features excavated at the site. This approach fits into the cyber-archaeology paradigm proposed by Forte (2016) by utilizing archaeological visualizations to contextualize subtle spatial continuity and history-making at Çatalhöyük. These visualizations help stimulate discussion and interpretation by enabling the visualization of multiple strata, discoveries, and datasets. Connections that were not identifiable in a standard 2D plan or photograph are now visible in 3D reconstructions utilizing the game engine Unity 3D or through interpretative infographics. Here, visualizations assist in the rendering and reconstruction of past places. They provide a clear representation of a complex construction sequence at Çatalhöyük by showing how building practices are replicated or modified across the entirety of the site's stratigraphy.

Immersive virtual reality also incorporates the sense of hearing whenever possible using sonifications and auralizations. The benefits of incorporating other sensory modalities are also evident in Augmented Reality, according to Graham et al. (2019). Graham et al. (2019) explore how seeing the past goes beyond just the sense of sight. They consider how AR assists in bringing the past to life through interaction with the present. They also call attention to a key issue with many current AR approaches that are ocularcentric and exclude or underutilize sound. Graham et al. (2019) argue that the existing visual-focused AR approaches create a break in presence that cancels out an immersion AR offers. Therefore, in order to prevent a break-in immersion, a focus on "hearing the past" is more effective and affective for immersion than a singular focus on sight. Their work illustrates how past worlds can often be better heard than seen, but unfortunately, sound and hearing remain underexplored compared to sight and seeing. While the introduction of past sounds into the present produces an anachronistic space that could potentially disrupt an immersive experience, at the same time, the use of these sounds in AR prompts more in-depth cognitive examination by the person experiencing the sounds.

Historical sounds evoke an emotional response in people that alter their understanding and memory of past events. Sound plays a major role in how memories are recollected and how they can potentially be altered by new experiences. Graham et al. (2019) demonstrate the importance of paying attention to sound in the present as much as in the past. To truly understand the experience of sound in the past, we have to consider how people in the present experience those same sounds. This leap forward will require additional research that challenges vision as the primary sense in our research and reconstructions of the past. The three projects listed below demonstrate the importance of going beyond vision as our primary sense in reconstructions using immersive Virtual Reality (VR).

The MayaCityBuilder project uses an Immersive VR headset to Incorporate vision with sound to facilitate an embodied experience to examine potential locations of ritual performance and determine participants' placement in these events (Goodwin and Richards-Rissetto 2023). GIS and 3D technology were utilized to measure sound propagation and reverberation in the urban core of ancient Copán as a case study to create a synesthetic experience in ancient Maya cities. The Ancient Maya culture and architecture provide an excellent opportunity to investigate the potential of GIS and VR modeling to better understand the built environment in producing multi-sensory experiences (Houston, Stuart, and Taube 2006). This case study from Copan illustrates the powerful role digital technologies may play in understanding the Classic Maya views of the body, sensations, and experiences. While the ancient Maya's exact experiences are impossible to replicate, we can investigate the variables that affected their sensory experience to begin to move forward in our phenomenological understanding of the past. These variables are evident in the ancient Maya's places, architecture, and material culture that archaeologists study. By understanding these variables, the reconstructions archaeologists produce are potentially more effective and immersive.

One of the projects that is part of IDEA (Isabella d'Este Archive) is called the Virtual Studiolo (Shemek et al. 2018). This project produced an immersive VR reconstruction of the multiple rooms that make up the Italian Reissuance- era Palazzo Ducale of Mantua, which housed Isabella d'Este's courtly collection of instruments, antiquities, and pieces of art. Extensive cultural heritage is made accessible through museum or CAVE spaces, photogrammetric models, 3D visualizations, and digital animation to create an immersive VR experience by reuniting a collection of artifacts currently dispersed across museums. Shemek et al. 2018 allowed users to interact with the Virtual Studiolo in both analytical and creative ways by calling attention to scholarly understanding of the Studiolo, yet also allowing for interaction, experimentation, and other forms of engagement to create a meaningful learning experience that is a mix of research and game. In addition to visual elements, acoustic elements were recreated according to the historical record. Though this project is a hypothetical and engaging remix, it alters and deviates from the original but in a way that promotes new ways of understanding d'Este and the broader Renaissance culture she was a part of by enabling the possibilities of multiple reconstructions that represent different interpretations. A 3D virtual reconstruction can be connected to datasets of documents and vice versa. While it is not an exact reconstruction of the original, the immersive experience it offers enables one to test a variety of hypotheses about display and curation during the Renaissance.

An immersive VR reconstruction of Le Boulogne, an 18th-century French merchant ship was successfully produced by Barreau et al. (2015). To better understand daily life and experience aboard the vessel, Barreau and team utilized historical documents, naval architecture plans, and archaeological data to produce a 1:1 scale 3D model of the ship. This model was then employed within a VR simulation of a ship sailing on the ocean. Beyond the animated buoyancy of waves, there was also an emphasis on reconstructing a sonic environment that mixed spatial audio such as birds flying by with a global soundscape of ocean and wind noises. Through this immersive visualization, a better understanding of life on board such a historical vessel is potentially possible. Static and strictly visual VR reconstructions should no longer be the endpoint for archaeologists. Mixed reality allows reconstructions that can visualize and interact with the past. Barrreau et al. (2015) argue that immersion within a 1:1 scale interactive environment enables better evaluation of material culture's role in past societies. Their production of a model and simulation incorporated historical sources in a virtual reality environment. The architecture of the ship and the interior spaces are enhanced using the movement and perception of the researchers to create a more immersive experience overall.

Video Games, 3D Models, and Virtual Worlds

Engines intended for video games such as Unreal and Unity are an excellent example of digital tools that create a multisensory interactive virtual environment. The implementation of sights and sounds are more immersive and are important in the creation of meaning within spaces, digital or otherwise. Sound allows for embodied interaction and helps in mediating the interaction between player and virtual space (Collins 2013a; 2013b; 2013c). When players interpret and explore virtual spaces at their own pace, those virtual spaces become the place if you will where meaning is produced.

The utilization of 3D models and v”rtua’ worlds together promote experiential learning in the Digital Humanities classroom (Bozia 2018). Digital technology allows for an archaeologist to create 3D models of artifacts and virtually reconstruct site features for utilization in research and/or outreach. Bozia (2018) focuses on experiential learning through virtual reality as a method that engages with students through 3D models and virtual reconstructions. Students learn through a multisensory experience that incorporates visual and audio means of engagement. Bozia (2018) argues that these reconstructions of ancient spaces and the performance held within them creates a more engaging, realistic experience and provides students with a sense of “being” within an otherwise virtual reconstruction. In addition, it shows how accurate spatiotemporal information is important for reconstructing comprehensions of ancient spaces. Once accurate spatiotemporal information is acquired a virtual reconstruction can created for direct user interface and experience.

VR and the Senses

Archaeological data is well suited to 3D representation, especially since many archaeological sites are not widely accessible to the public (Knabb et al 2014). There is a long history of archaeologists documenting their findings through maps and illustrations as well as photography. However, 2D images and representations fail to capture the full scale of sites and artifacts. Virtual reality modeling offers the potential to bridge this gap. In addition to allowing researchers to reexamine discoveries and objects at various scales, VR environments are also heuristic tools enabling one to investigate the relationships between artifacts, features, and other aspects of the environment.

There is a propensity to focus on what things looked like, rather than how they were used and experienced (Eve 2018). 3D models are limited to a screen or 3D printed material (Eve 2018 pg. 114). The smells, sounds, and feel of an object are lost in these 3D reconstructions. Archaeological illustrations generally focus on attributes that are usually stylistic, like form and do not usually attempt to reflect the multi-sensory elements of the object. My experiment will focus on representations of archaeological spaces that aim for a multi-sensory representation of an environment and provide a counter balance to ocularcentrism or visual bias that is prevalent in archaeological research (Thomas 2008). An overreliance on current technology In the production of 3D representations Is heavily focused on the visual aspects at the exclusion of non-visual sensory modalities.

"The deduction of intangible attributes from fragmentary tangible evidence is the most challenging responsibility of historical disciplines" (Scuito et al 2023 pg. 93). VR platforms enable visualization of the interpretive process and a digital linking between various physical findings. This multisensory engagement provides for user-centered analysis of the models. Understanding sensory responses to VR models helps maximize the transfer of potential information such as the appearance and location of archaeological artifacts or features. Users develop a sense of presence in an immersive environment through a precise representation of space, consistency in object behavior, and auditory mapping. Rather than focusing on only sensory accuracy, the focus becomes one of experiential analogy. Despite a lack of tangible evidence of sound in ancient Roman sites, multiple possible interpretations of sensory experiences were made possible by Scuito et al. (2023). Sound was treated as situational in both space and time (Scuito et al. 2023 pg. 94). Sound settings, such as reverberation, was set to analogue, and an impression of a pre-industrial setting was devised focusing on natural sounds like rain and artificial man-made sounds. This approach enabled the creation of multiple sound configurations. Contemplating sounds in the VR environment brings up questions of how sounds and their meanings are shaped by cultural, economic, and political contexts.

VR offers the possibilities to reconstruct and manipulate archaeological material or phenomena that can no longer be seen, making it an appealing tool for learning about objects and processes. However, this learning can only be achieved if physical and virtual experiences are multisensorial and intuitive (Tost and Economou 2009 pg. 161). Visitors surveyed by Tost and Economou (2009) in one study consistently found that VR offered a feeling of experiencing the past, which made it better for them than only text. This is perhaps due to the experiential nature of new media, which conveys knowledge in a manner different than that of text and provided another positive example of research focused on the enhanced user experience of immersive VR.

Sound in VR and the Experience of Past Landscapes

To better understand the past, it is helpful to gain a better understanding of the sounds that could potentially be present within a environment, as well as how those environments might affect those sounds (Murphy et al 2017) and what people in the past might have heard. Considering sound and our acoustic heritage enables us to construct a multisensory view of the past. Sound plays an important role in conveying a variety of information as well as creating engaging and immersive multimedia experiences. This demonstrates the importance of sound as a vehicle to better understand the past and the role of creating representations that accurately reflect sound in archaeological spaces.

Understanding how contemporary people are affected by sounds and acoustics of an archaeological site may lead to a better understanding of how past individuals' experiences were shaped by sound (Valenzuela et al 2020). Interdisciplinary discussion is important to bridge separate spheres of influence between researchers and scholars regarding how one extracts the cultural dimensions of sound and acoustics from an archaeological site. Impulse responses and others means of reconstructing the acoustics of past environments are limited if the site is not fully intact, and simulations and models have many assumptions built into their interpretations. A virtual reality system, however, can enhance the sensory experience by creating the illusion of a space with the appropriate acoustics and presence of people.

Movement in VR and the Experience of Past Landscapes

Movement whether it be actual or virtual plays a major role in perception and shared understanding amongst people and is vital to understanding sensory experiences past and present (Lash 2022). Movement through landscapes is key to creating embodied knowledge and is therefore a major aspect of phenomenological analysis in archaeology. Materials enable and constrain human capacities to sense and engage with other materials and life forms in the world. Digital reconstructions of those landscapes and materials provide a means of evaluating how people experienced the world around them in the past. Digital representations require scholars to deal with questions they might otherwise ignore when considering experience in the past. In addition, quantitative assessments of user experience within a virtual landscape are possible. This chapter demonstrates that any discussion of the senses in archaeology requires a consideration of movement. Quantitative analysis of user's movement through a VR environment is an important criterion to my experiment.

Improving Perception of Archaeological Material Through Digital Approaches

Archaeological interpretation benefits by 3D modeling in addition to supporting communities in maintaining their cultural identity (Dawson et al 2011 pg. 388). Physical artifacts are often viewed as having more "heft", authority, and permanence to them. While digital products are considered superficial, and temporary (Dawson et al 2011). There is value in a virtual experience that they can carry as much 'weight' as the physical artifacts they represent and demonstrates that technology enables once passive observers to become active participants.

Manipulation and tactile perception of objects is important to understanding them, but visitors to museums and archaeological sites are often restricted from directly handling artifacts (Di Franco et al 2015 pg. 243). The emphasis is on visual engagement without utilizing the other senses. 3D technologies offer a path forward for enhancing experience of artifacts and going beyond the inability to handle cultural heritage. VR allows for interaction that even while non tactile helps create rich and immersive experiences. 3D printing enables the creation of 'new' objects for sharing with the the public. Both new means of presentation improve sensorial experiences with the past, and present new research questions on "how people negotiate with the inauthentic". Di Franco et al. (2015) are interested in determining how people engage with 3D digital copies of artifacts, 3D prints and digital reconstructions and how these experiences differ from the visual experience of the original artifacts or handling of a 3D print. "Little is known about how people perceive past material culture through the senses, and how experiencing ancient artifacts through different media affects the perception of our past" (Di Franco et al 2015 pg. 244).

The media used In the presentation of artifacts affects how they are perceived (Di Franco et al 2015 pg. 260). For example, immersive VR experiences convey similar color and weight perception to the original artifacts, while the 3D prints are not always as effective. The immersive visualizations better overall interpretation of textures. The results of the Di Franco et al (2015) experiment suggest that people want an immersive tactile experience with artifacts, even if the artifacts are perceived as inauthentic and prefer to experience an object through their senses, rather than having an authentic experience of the original artifact. This suggests displays of artifacts should provide an active experience with visitors and emphasize a kinesthetic engagement. New technology is not perfect, but it produces new engagement, attention, and curiosity about past material culture. “Our paper shows that people like to engage with new technologies to understand ancient artifacts and points to the integrated use of traditional displays, 3D immersive systems, and 3D prints as an effective way to increase perception, understanding, and engagement with artifacts” (Di Franco et al 2015 pg. pg. 261).

Combining VR and Qualitative Experiments

Opitz (2017) studied the movement of individuals and their visual attention through a digital environment built using realistic lighting and detailed 3D models. What is visible as an individual walks through the digital environment is recorded and analyzed for visual saliency based on attention directed at specific areas in each scene. A dataset is constructed from a combination of visual saliency maps and images that relate to what is visible in each moment. This helps one understand how the location of features within space affects the visual salience of a space allowing the identification of visually salient areas without culturally specific knowledge, separating what we think is culturally interesting into what is attractive to visually. This Opitz (2017) experiment is important because it is an example of successfully combining archaeological data, VR, and basic research to run a qualitative experiment.

Kern and Ellermeier (2020) studied how the introduction of auditory stimuli to a virtual environment influences presence, or the feeling of “being there”. Kern and Ellermeir (2020) separate immersion and presence. In Kern and Ellermeier (2020), presence is the subjective feeling of “being there” while immersion is “the technical potential of presenting a virtual environment”. Kern and Ellermeier (2020) argue that auditory stimuli complement visual stimuli, as auditory perception can compensate for limitations of visual perception. The auditory system compensates for the restricted nature of the visual field, and sound provides a temporal aspect to perception that a static visual field cannot. In order to understand how sound can enhance presence, Kern and Ellermeier (2020) made use of a head mounted VR display in combination with stereophonic sound derived from environmental sounds in the VR environment, as well as sounds generated by the footsteps of participants. Their primary research question aimed to understand what sounds enhanced the presence to the greatest degree. Participants in the experiments moved along a gravel path in a virtual environment where they were exposed to several ambient sounds as well as sounds with localizable origins such as the bells on a church. Upon completion of the VR experience participants completed a presence questionnaire. This questionnaire focused on the effects of the audio elements in the VR environment. The results of their experiment suggest the reproduction of an appropriate soundscape in combination with a visual environment plays a major role in enhancing presence, realism, and involvement. A second experiment demonstrated that a realistic step-reproduction algorithm greatly influenced perception of the soundscape. Each of the experiments showed measurable increases in presence when sound was added. Kern and Ellermeier (2020) conclude that further studies should explore how sound can assist in spatial orientation or even solving a spatial task. This study is relevant to my own experiment because it demonstrates how to successfully implement and run a multi-modal VR experiment. In addition, it offers suggestions for underexplored areas of research in studying the role of sound in VR.

Hendrix and Barfield (1996) study virtual presence within a simulated environment. They argue that presence will increase if more sensory modalities are included within the virtual environment. The authors believe that both presence and realism will increase within the virtual environment because of the addition of auditory cues and an experiment. The first compares user experience in a virtual world with no sound vs. spatialized sound. The second compares user experience in a virtual world with non-spatialized sound vs. spatialized sound. They note that externalization of sound sources in a virtual environment are reliant on how stimuli in that environment approximate factors such as head movement or reverberation. Otherwise, the sound may appear to be coming from inside rather than outside the user's head. For this reason, the authors predicted an increase in both presence and realism with the addition of spatialized sound. After exploring the virtual worlds participants took a small questionnaire that evaluated their sense of presence and realism. The results showed noticeably improved presence when sound was present in comparison to no-sound. However spatialized sound did not seem to increase an impression of overall realism. The authors expected more sensory modalities to lead to more realism, however they suspected that participants may have been overly focused on the visual realism rather than the auditory as well. This article has implications for my experiment. It suggests that participants in my experiment who experience a VR environment with sound will have a more engaging experience than those without.

Creation of a VR Environment

The following will provide an overview of how the VR environment used in the dissertation experiment was designed and created. It explores the pitfalls and challenges encountered as well as how they were overcome. Simultaneous location and modeling (SLAM)-based Lidar data was collected at the site of Las Cuevas in Belize using an Emesent Hovermap over the course of several days during the 2022 field season (Lozano Bravo et al. 2023). The advantage of the Hovermap is the user can collect data while on the move. This is especially Important In a cave where the floor is often uneven with numerous visual obstructions. The initial data collection resulted in numerous large 3D point clouds. The scans were outputted as .Las files and scaled to the appropriate size. Next, the scans were aligned into a singular 3D point cloud. This required the use of the software Leica Cyclone REGISTER 360 PLUS to manually align each of the 38 scans collected at the site. After aligning the scans, a noise filter was applied to the data to remove noise surrounding surfaces as well as isolated points (Lozano Bravo et al 2023 pg. 121). The final point cloud of Las Cuevas was 4.1 billion points. The main purpose of the study was to create a basemap for use in GIS (Lozano Bravo et al. 2023.

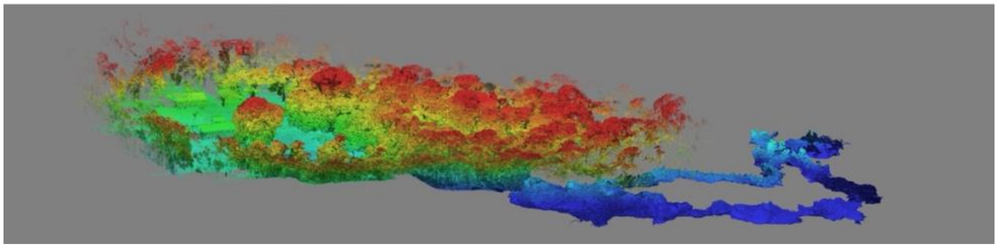


Fig. 1: The fully aligned pointcloud of Las Cuevas (Lozano Bravo et al. 2023)

The creation of a virtual environment utilizing VR was a main objective of my dissertation. Since a decision was made to focus on the entrance chamber, this section of the cave needed to cut from the final point cloud of Las Cuevas. The 3D. point cloud processing software CloudCompare (CloudCompare, 2022) was used to complete the process. This involved removing all but the entrance chamber from the larger point cloud. The next step was sub-sampling the remaining point cloud to reduce the number of points to a size that could be easily used to create a mesh. It was determined as the project continued that a point cloud of around 10 million points would create a viable mesh for import into the the 3D computer graphics game software, Unreal Engine. The mesh was created using the Poisson Surface Reconstruction plug-in in CloudCompare, a triangular mesh generation algorithm that enables the construction of 3D surfaces from point samples (Kazhdan et al. 2006). The primary parameter that is adjusted in the creation process is ‘octree depth’. The higher value gives finer detail to the model but uses more time and memory in the creation process. An octree depth of 13 was identified as the ideal number to use. Any lower and the cave mesh lacked recognizable details. Any higher and the model became too cumbersome to use effectively in a game engine such as Unreal. After the mesh was created, it was exported as an .OBJ file and imported into the 3D mesh processing software, MeshLab (Cignoni et al. 2008). Meshlab was utilized to remove artifacts and noise from the mesh that were not reflective of the actual cave, as well as filling in any holes that existed in the model. Next, the model was exported as an .OBJ format for importing into Unreal Engine 5.

Fig. 2: A comparison between the pointcloud of Las Cuevas entrance and the real world.

While multiple platforms such as CryEngine and Unity3D exist for creating a VR environment, such as Unreal Engine was determined to be the best option for several reasons discussed here. The first is Blueprint Visual Scripting, a node-based scripting system for the creation of gameplay elements using tools that are typically only open to people with programming knowledge. While it has a learning curve, it allows one to create two vital features of a VR environment: user controls and player location tracking. Unreal Engine 5 also has a feature-rich audio system for realistic simulations. Perhaps the most important feature is the sound spatialization controls that simulate orientation, attenuation, propagation, occlusion and obstruction, and reverb. These features allow the creation of a more engaging and immersive auditory experience. Additionally, Unreal Engine 5 has impressive visuals due to its design origins in first-person perspective centered on weapons-based combat, while game engines like Unity are aimed more at 2D and casual games and gamers.

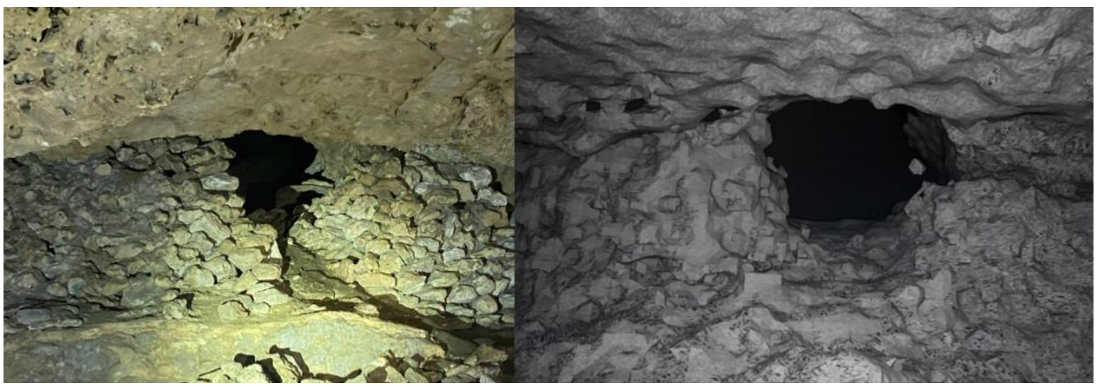


Fig. 3: Blockage 1 at the end of the entrance chamber. Real world vs. game engine comparison.

Once the model is brought into Unreal Engine 5 several steps are required before utilization is complete. The first step was creating a collision model for the cave model. A collision model determines where the user physically collides with the model. Two options for collision models exist in Unreal Engine 5: simple and complex. Simple resembles a simple geometric shape like a rectangle or square. While this is not computationally intensive, it fails to create collisions consistent with an actual object. For that reason, a complex collision model was chosen despite being more memory intensive. The complex collision model accurately conforms to the shape of the cave and ensures proper affordances and constraints while moving through the space. It was also necessary to create a system for navigating the VR environment. Several options ranging from teleportation to flying were explored. For the sake of immersion and feel, it was decided that grounded, steady movement through the environment would be the most ideal. The in-game avatar would be controlled from a first-person perspective using an HTC VIVE headset and controllers. The headset tracks head motion and one of the controller's touchpads controls direction of movement in the VR environment. Settings were also put in place so that the avatar would not get stuck on any surfaces or objects in the environment.

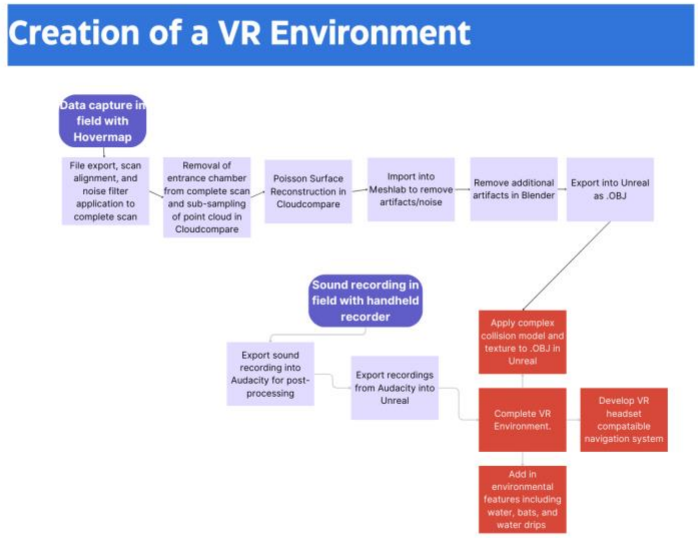


Fig. 4: A flowchart demonstrating how the VR environment came together.

Environmental Features in a VR Environment

In addition to the creation of the cave model, environmental features had to be incorporated to complete the immersion and enhance user engagement with the overall experience. The first environmental feature added was water. The built in water system in Unreal Engine was used to create the water found at the bottom of the cenote, a sinkhole resulting from the collapse of limestone bedrock that fills in with groundwater. It was a straightforward process that involved the creation of an editable water surface sized to fit the desired area. To create the appearance of rainfall, the freely available Realistic Starter VFX Pack Vol 2 Pack for visual effects content was downloaded from Unreal Engine (https://www.unrealengine.com/marketplace/en-US/product/realistic-starter-vfx-pack-vol). This contained a water dripping effect that could easily be suspended in the air above the caves dripline to create the appearance of rain. Since the opening of the cave faces outside, the landscaping tool was used to sculpt a hill in-front of the entrance. To avoid a plain surface, several types of tropical vegetation props were added to enhance the entrance. These also came from the above www.unrealengine.com link, and while not necessarily the exact species of plant found outside the cave, they added the appropriate tropical appearance to the exterior. Bats were added to the VR environment using the Niagara Bat System purchased from Unreal Engine. This easy-to-use system provided several bat meshes with added flocking behavior allowing the bats to fly in and around or roost in certain areas or locations. In addition, bat behavior towards the avatar is controllable with behavior ranging from ignoring the player to flying away from them. Realistic lighting was also added to the VR environment as well. Directional lighting was used to have light shine into cave through the entrance reflecting the real-world environment. This lighting had its brightness adjusted to reflect the decay of the light as it is unable to reach the back of the entrance. “Worldwide” environmental lighting was added to give the sense of normal daytime lighting with a visible sky as well.

Fig. 5: An example of one of the environmental features added to the VR environment.

Recording Sound for a VR Environment

Two handheld recorders captured sounds for the VR environment over the course of two field seasons. A Zoom H4N and Zoom H3-VR recorder were used during the first and second field seasons respectively. These handheld recorders are battery powered, lightweight, and portable. This made them for working in a cave environment as heavy or cumbersome equipment would be difficult to maneuver, especially through tight squeezes or narrow passages. Caves can be rather quiet environments, but several recording opportunities do exist and enhanced the final product.

Post-recording the sound was edited using the digital sound editing and recording software Audacity. Audacity was used to review sound recordings for quality as well as any potential issues such as unexpected background noise. Caves can be a very quiet environment and even slight movements by the recorder may be accidently picked up. If possible, sound files were spliced to remove such sounds and preserve the overall recording. In addition several sound files were combined into singular files in order to create a longer overall recording of a specific sound such as bat vocalizaitons or water dripping.

Fig. 6: Handheld audio recorder setup in Las Cuevas.

Sound in A VR Environment

Several audio processing techniques are utilized to produce a virtual acoustic environment that mimic physical phenomenon (Garner 2018 pg. 276). Environmental modeling tools such as occlusion and obstructions are the primary ones. Occlusion is when an obstacle muffles both the sound wave and its reflections. Obstruction only muffles the direct sound wave. An example of occlusion is shutting a door between two rooms; in obstruction, the door is left open as the player moves towards the other side of the room. The most basic virtual models of occlusion and obstruction utilize a binary effect. The sound is either audible or muted. More advanced models will attenuate sound relative to the location of the listener and material properties of an obstacle. Like any effect, occlusion, and obstruction deal with challenges of balancing physical accuracy and realism with computational power. A more complex acoustic model will lead to greater realism, but at the cost of greater computational power requirements. In addition to occlusion and obstruction, convolution is useful as well. Convolution is filtering an audio sample by the spectral frequency of another (Garner 2018 pg. 279). Convolution reverb makes use of an impulse response taken from the real-world to filter a sound wave. Impulse responses are acquired by playing a sine wave sweep, a tone that increases in frequency and decreases over time, within the real-world acoustic environment. A microphone records the soundwaves from this tone. The spectral composition of the recording is analyzed against the sine wave to infer acoustic properties as well as produce an impulse response. An Impulse response may be applied to audio samples to create sound that appears to be in the identical space. Spatialization also plays a role as role in creating effective sound in VR environments.

Spatialization is the ability of an audio system to position sound objects within localizable points in 3D space (Garner 2018 pg. 281). Sound is given a perceptual quality of spread and/or position across a virtual space in the form of stereo panning, surround sound, and 3D/positional audio. It can greatly enhance even non-spatial audio samples. The spatialization technique most relevant to VR sound is head-related transfer function (HRTF). HRTF is the Fourier transform of head related impulse response (HRIRs). Sound waves filtered by the acoustic effects of the head and toros upon incoming sound waves before they can get to the middle ear. VR SDKs and plug-ins often feature HRTF processing, enabling it to be used without the need to conduct HRIR capture. Finally, distances effects are also used in VR sound. Audio processing techniques produce a sense of proximity between sound objects and the user in an often-simplified form such as minimum/maximum attenuation thresholds (Garner 2018 pg. 283). It is a simple concept in which closer objects are louder and more distant objects are quieter. A minimum threshold determines when the sound will start to lower, and the maximum value determines when the loudness reaches zero. Sound decay or attenuation across a space is important to the immersive VR experience. It adds to the experience by providing a sense of scale and distance within the environment. As the user moves through the space sounds become gradually louder or softer depending on where they go.

Bottlenecks in the VR Creation Process

Several bottlenecks emerged in the creation of the VR environment that slowed progress to varying degrees. The first bottleneck appeared in the processing of the 3D point cloud scan of Las Cuevas. This occurrence highlighted the problems of working with data-rich sets for research and determining what is elastically feasible working with large point clouds on consumer grade computer equipment. The final point cloud of Las Cuevas was several billion points and was cumbersome and unwieldy to work with. Agisoft Metashape proved to be the only software that could open the file without crashing or severe slowdown. A bottleneck occurred when decisions needed to be made on how much of the cave point cloud would be used and at what detail. The point cloud was subsampled at several different levels of detail which were exported as .LAS files. These files were then imported into CloudCompare, a 3D point cloud processing software. In CloudCompare, steps were taken to create a mesh. First, normal were computed, followed by running Poisson Reconstruction to create the actual mesh. It quickly became apparent that point clouds larger than 10-15 million points could not be easily processed into meshes using CloudCompare. If the software could process them, the resulting mesh was often too large and bulky to be imported into Unreal Engine. As a result, a mesh limited to only 1-2 million faces could easily be utilized. However, in the process of scanning the cave, several people remained in the scans. This necessitated importing the mesh into the software Blender for further editing. It proved to be slow and tedious to remove people from the scan without accidently cutting out parts of the cave itself but in the end, proved doable and was successful.

A second major hurdle occurred working within Unreal Engine. Since it was not possible to create a singular mesh from the complete scan of Las Cuevas, a total of 10 meshes were utilized representing various chambers and tunnels within the cave system. Because the meshes were not connected, a means of moving between them was created. The first attempt created artificial tunnels between each mesh but that proved to be highly immersion breaking due to the artificial appearance of the tunnel tubes. The second attempt involved the development of a teleportation system between chambers. This involved the participant moving onto a platform which would teleport them to the next chamber and vice-versa. This proved problematic as participants often struggled to find the teleportation platforms in each chamber and it was also found to be highly immersion breaking. Finally, a decision was made to focus entirely on the large entrance chamber. Focusing on the entrance chamber allowed the addition of more detail such as dripping water, spatial audio, and flying bats. In addition the lack of awkward transitions between chambers prevented any unnecessary breaks in immersion for the user.

An additional roadblock encountered in Unreal Engine was developing a means of player movement. The first attempt at player movement involved a floating avatar that could move in any direction with minimal resistance. The ability to move in any direction with no grounding proved to be disorienting to participants as the low lighting and similar surface texture in the cave made it difficult for the participant to orient themselves easily. This roadblock was solved by grounding the user entirely and adding weight to their avatar so they could not easily fly off in any direction or angle.

Survey of VR Participants

A survey was conducted in order to evaluate the effectiveness of the VR environment. A total of 30 participants took part in the experiment; 15 participants experienced the environment with sound and 15 participants experienced it without sound. The survey was divided into two parts: (1) A pre-experience demographic questionnaire and (2) a post-experience questionnaire. The demographic questionnaire included the following questions:

1. What is your gender?
2. Do you have normal vision and hearing?
3. Have you been in a cave before?
4. Have you ever been to an archaeological site before?
5. How interested are you in archaeological and historical sites?
6. Are you someone that plays video games?
7. Have you used VR equipment before?
8. How comfortable are you with using virtual reality technology?

Questions 3-8 were based on a scale of 1-5. These questions intended to evaluate familiarity with caves and archaeological sites as well as gauge interest in them. In addition, the questions aimed to understand how participants might handle using VR equipment and experience a VR environment. The post-experience questions aimed to evaluate user engagement and immersion within the VR environment. These questions were inspired by two articles that evaluated engagement and immersion in video games (Jennet et al. 2008, Weibe et al. 2014). The following questions were asked:

1. When I was in the cave, I lost track of the world around me.
2. I blocked out things around when I was in the cave.
3. The time I spent playing the game just slipped away.
4. I felt anxious while I was inside the cave.
5. I felt disoriented while I was inside the cave.
6. I lost myself in this experience.
7. I was absorbed in this experience.
8. To what extent did the experience hold your attention?
9. How much effort did you put into exploring the cave?
10. To what extent did you lose track of time?
11. To what extend did you feel consciously aware of being in the real world while playing?
12. To what extent did you forget about your everyday concerns?
13. To what extent were you aware of yourself in your virtual cave surroundings?
14. To what extent did you feel like you were interacting with the cave environment?
15. To what extent did you feel as though you were separated from your real-world environment?
16. To what extent was your sense of being in the cave environment stronger than your sense of being the real world?
17. To what extent did you feel as though you were moving through the game according to your own will?
18. To what extent did you find navigating the cave challenging?
19. Were there any times you wanted to give up?
20. To what extent did you enjoy the graphics and imagery?
21. To what extent did the cave feel alive?
22. How would you say you enjoyed being in the cave?
23. Would you like to go to the cave again?
24. Would you want to visit a cave in the real world?

Except for question 23 which was a binary yes or no, all questions were on a likert scale of 1-5 with 1 identified as “not at all”, while 5 being “a lot” or “completely”. In addition to these questions, there was a space for any additional comments or questions that the participants felt were not addressed by the survey.

T-test Used on Survey Results

A t-test was conducted for each question to compare the results of answers by the participants. A t-test compares the means of two different groups to identify whether statistical evidence shows a significant difference in means. This is determined by whether the P value is less than the Alpha of .05. If it less, then it suggests a statistically significant difference in mean. Results were given as one tail or two tail. A two-tailed testdirec looks for both positive and negative differences. A one-tailed test only shows difference in one direction. In other words this showed when the average of one group was greater than the other without considering that it might be less.

T-test for Minimum and Mean distance of Player Location from Landmarks

Once the player movement data was logged and exported from Unreal Engine into Excel, a code was developed to extract the minimum and mean distance of each logged point relative to key landmarks such as the entrance and sounds locations. Once the minimum and mean distance were determined for both the sound and non-sound group relative to a landmark, a t-test was run on the results to see if the results were statistically significant. These results will be discussed in the next chapter.

Dissertation Chapter 4: Results

Memory Test

After the VR experience, the participants were given a written memory test. A total of 16 participants completed the memory test, 8 with sound and 8 without sound. The number of participants was lower in comparison to survey, because the memory test was not ready until sometime after the experiment had already had participants taking part. The test itself is placed below:

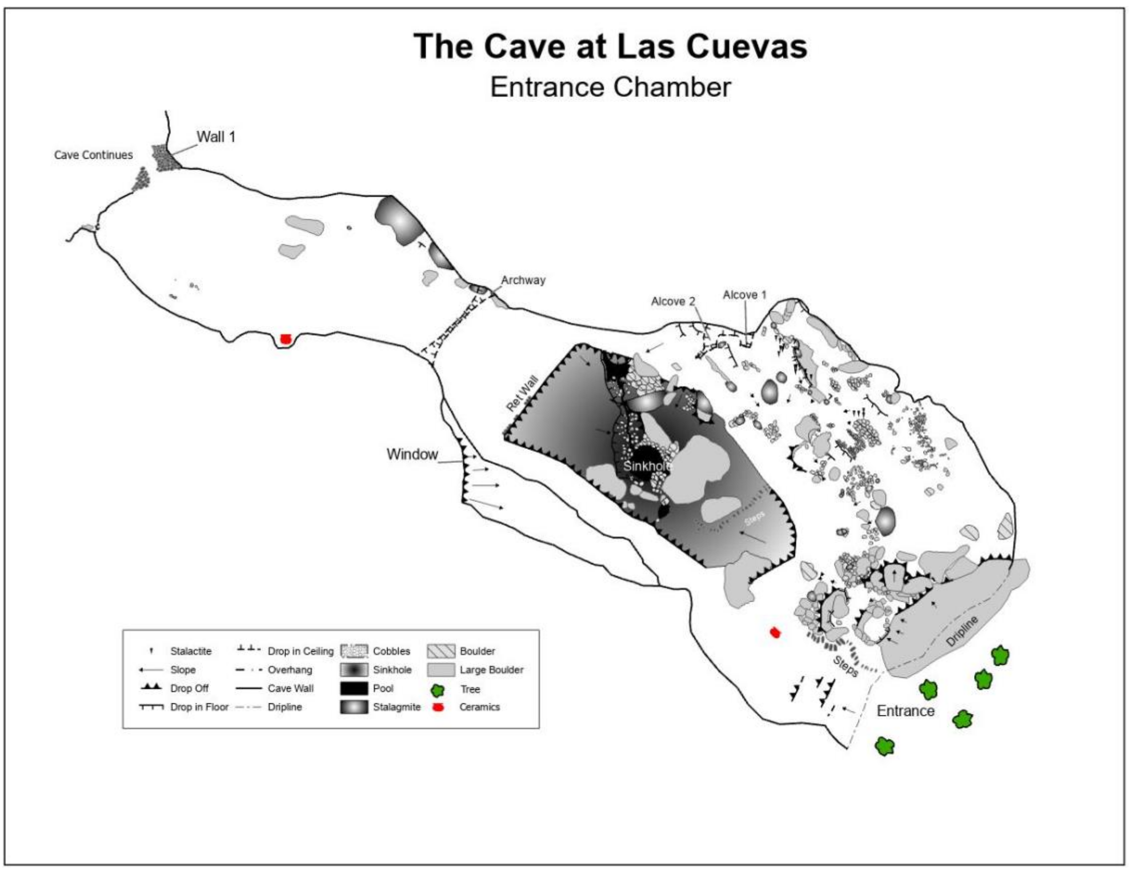


Fig. 1: Map of entrance chamber used in memory test.

Instruction: Please write in the number of the item where you think you saw it. If you did not see the item, please do not write it in.

1. Dripping Water
2. Bats
3. Standing Water
4. Stairs
5. Arrowhead
6. Insect
7. Rock art

The participants were not told that the arrowhead, insect, and rock art were not present in the VR experience. Participants completed a paper version of the map and results were compiled into an Excel spreadsheet.

Table. 1: Results of memory test.

Sound: 8 samples	Marked	Correct	Incorrect
Dripping water	4	1	3
Bats	6	4	2
Standing water	6	2	4
Stairs	4	1	3
Arrowhead	1	0	1
Insect	1	0	1
Rock Art	7	0	7

No Sound: 8 samples	Marked	Correct	Incorrect
Dripping water	5	1	4
Bats	5	2	3
Standing water	6	2	4
Stairs	3	1	2
Arrowhead	2	0	2
Insect	0	0	0
Rock Art	4	0	4

Post-Experience Survey Questions

After spending 5 minutes in the VR experience participants took part in a survey with a total of 24 questions. Participants with sound and without sound took separate but identical copies of the survey to keep results clearly separated. Except for question 23 which was a binary yes or no, all questions were on a linear scale of 1-5 with 1 identified as “not at all” and 5 being “a lot” or “completely”. In addition to these questions, there was a space for any additional comments or questions that were not addressed by any of the questions.

The following questions were asked with the answers from the participants who had sound shown first. Only the ones that showed significance in the t-test are shown below. The rest can be found in the appendices:

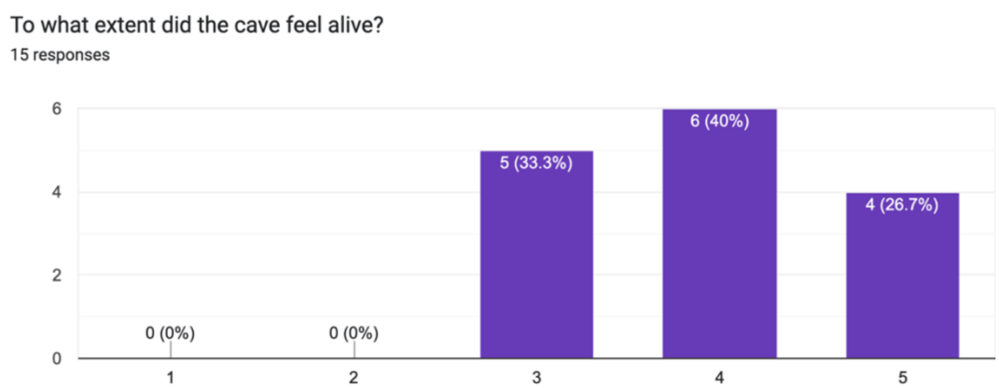


Fig. 2: Participants with sound.

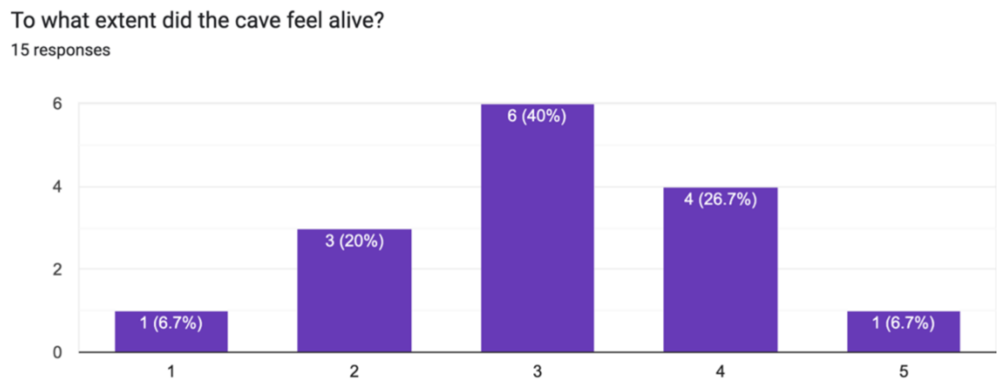


Fig. 3: Participants without sound. Participants with sound skewed towards the higher end of 3, 4, 5 while participants without sound skewed towards the middle around 2 and 3.

T-test of Post-Experience Survey Results

A t-test was conducted for each question to compare the results of participants answers. A t-test compares the means of two different groups to identify whether statistical evidence shows a significant difference in means. This is determined by whether the P value is less than the Alpha of .05. If it less, then it suggests a statistically significant difference in mean. Results were given as one tail or two tail. A two-tailed test looks for both positive and negative differences. A one-tailed test only shows difference in one direction. In other words this showed when the average of one group was greater than the other without considering that it might be less. In the results below, "variable 2" is participants with sound, and "variable 1" is participants without sound. Each consisted of 15 participants.

Table. 2: To what extent did the cave feel alive?

	Variable 1	*Variable 2*
Mean	3.066667	3.933333
Variance	1.066667	0.638095
Observations	15	15
Pooled Variance	0.852381	
Hypothesized Mean Difference	0	
df	28	
t Stat	-2.57079	
P(T<=t) one-tail	0.007876	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.015753	
t Critical two-tail	2.048407	

T-test of Player Movement

Table. 3: The results of the minimum and mean distance from various landmarks in the cave as well as a t-test comparing the two groups of participants results.

Landmark	No Sound min	Sound min	Min Distance T-Test
BA3	601.816	594.1921	0.03090096
BA12	709.107	754.0903	0.121220955
Cenote	381.342	290.2521	1.359838958
Flying Bats	617.739	601.307	0.046619044
Water Drip 1	651.753	509.72	0.52166868
Water Drip 2	800.399	860.105	0.153357263
Rain	838.321	728.067	0.621159369
Start	410.142	232.504	1.360554348
Exit	855.947	955.004	0.146261403

Landmark	No Sound mean	Sound mean	Mean Distance T-test
BA3	3692.644	3567.065	0.555719351
BA12	3825.609	3733.723	0.277283301
Cenote	2911.4	2647.995	1.02974106
Flying Bats	3685.413	3560.661	0.385260134
Water Drip 1	3407.588	3168.674	0.802193001
Water Drip 2	3981.578	3916.095	0.190520814
Rain	4843.702	4755.021	0.209455107
Start	4593.112	4375.705	0.545492012
Exit	5338.945	5371.083	0.076867947

K-Means

A k-means was applied to 20 different participants split evenly into a Sound and No Sound group. The average distance of participants from several landmarks as well as the closest individual participant was calculated. A t-test was then applied to (1) the average distance of all the participants to the landmarks in each group and (2) the minimum distance of all participants to the landmarks.

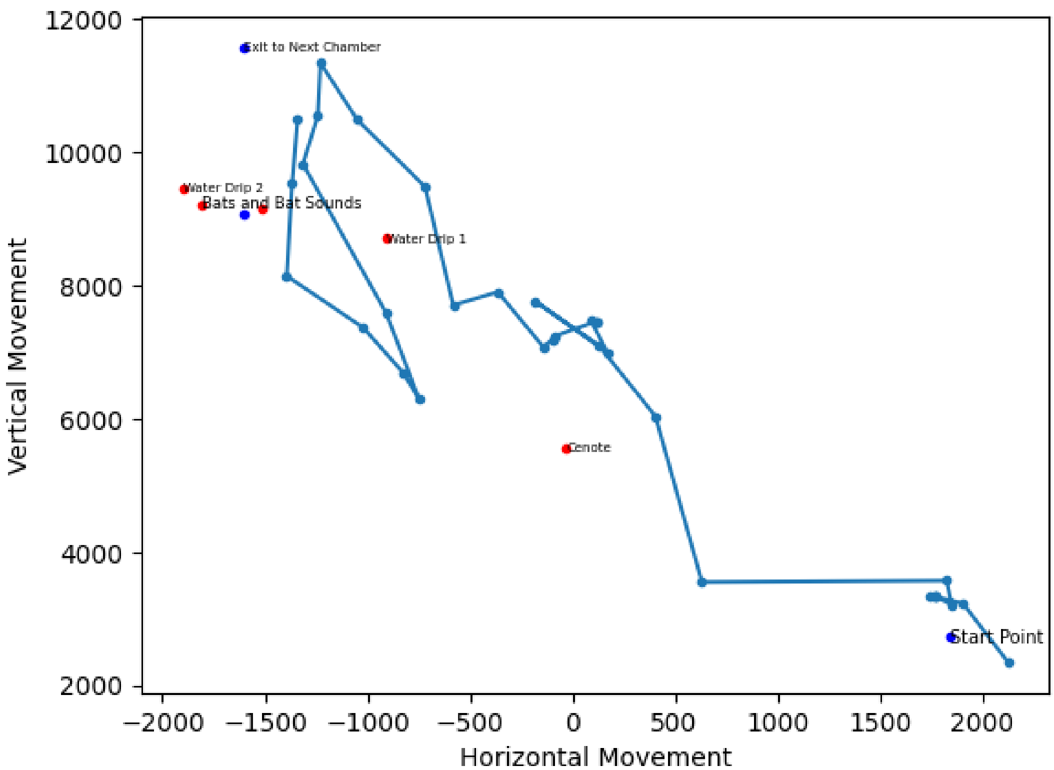


Fig. 4: The location of each landmark chosen for the K-means test relative to the movement of a sample player in the cave recorded as a blue line. Physical landmarks are blue, while auditory ones are in red.

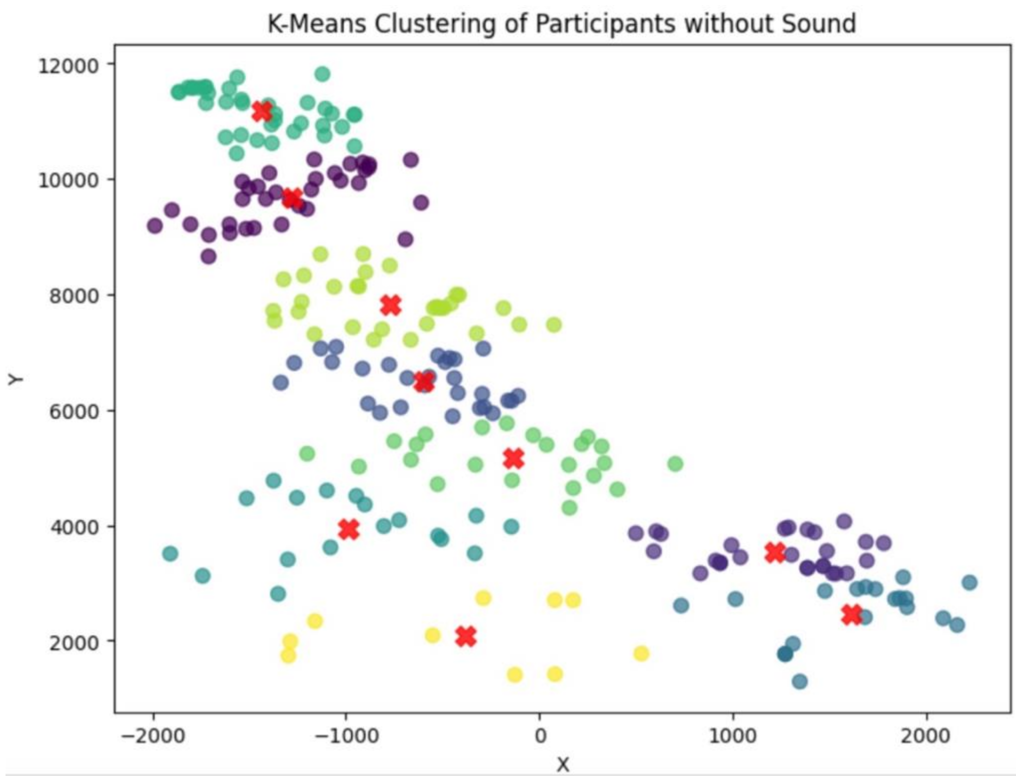


Fig. 5. This graph displays K-means clustering of player movement for participants without sound. Each of the 9 red X's represents the center of a cluster. Each cluster defined by the color of the points around the X.

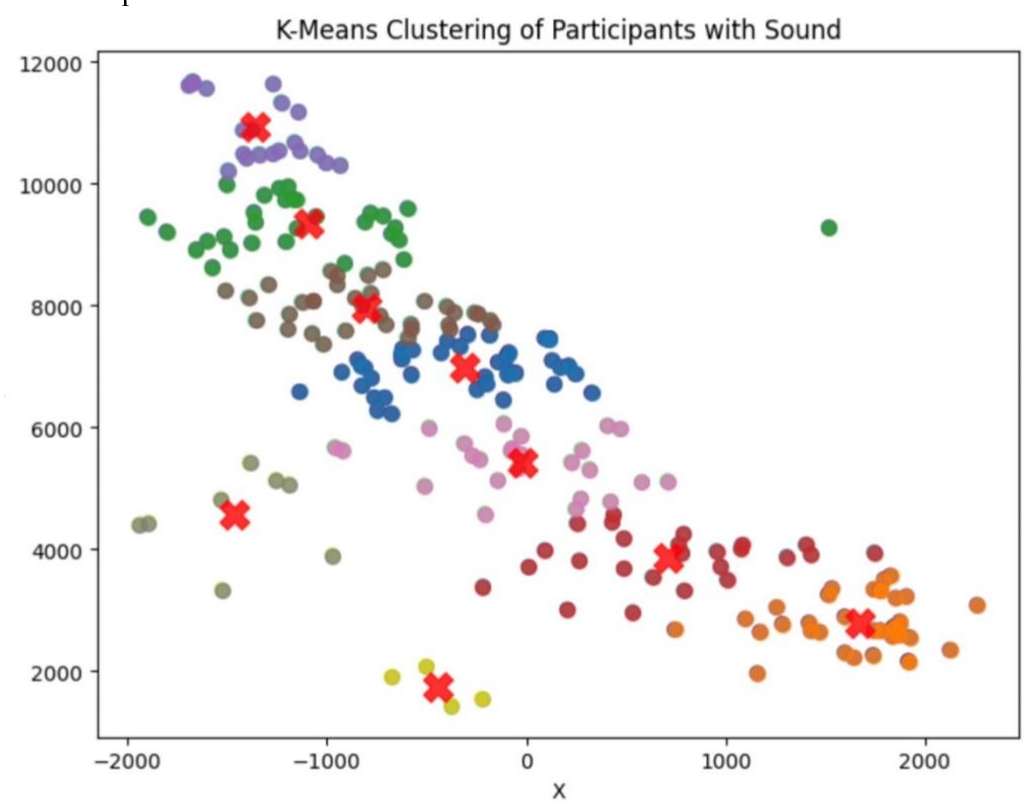


Fig. 6. This graph displays K-means clustering of player movement for participants with sound. Each of the 9 red X's represents the center of a cluster. Each cluster defined by the color of the points around the X.

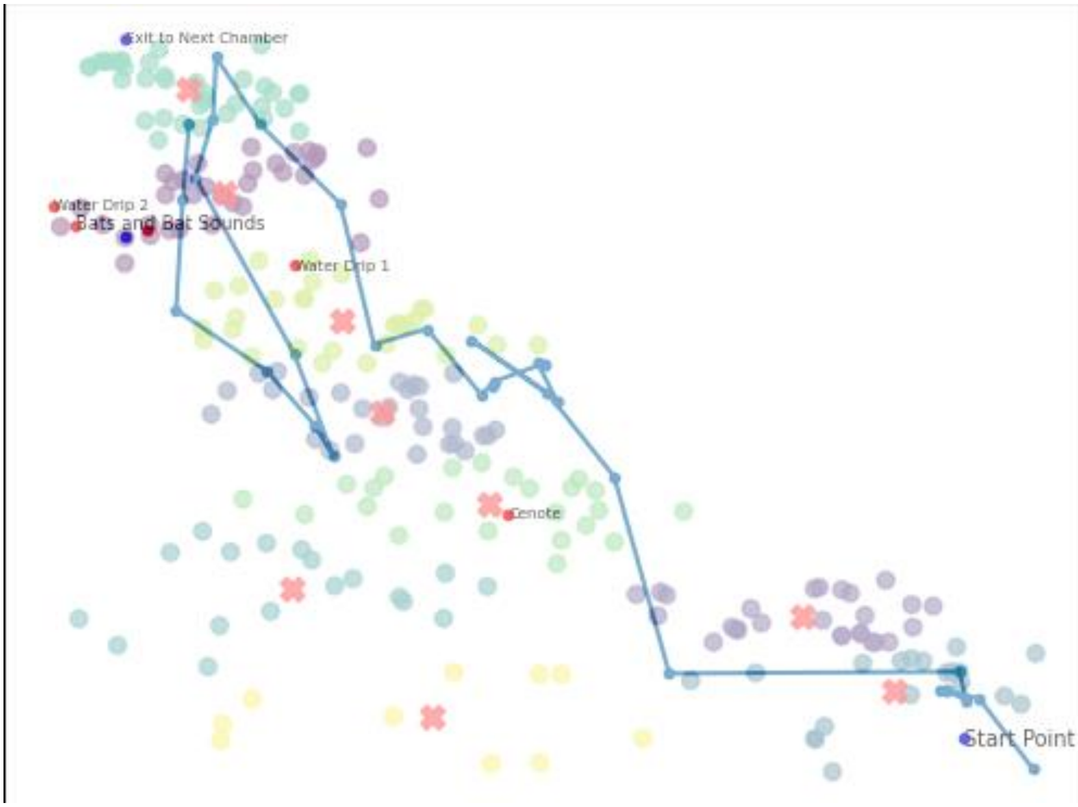


Fig. 7. The map overlays the sample movement from all participants and the location of landmarks in relation to clusters and cluster centers of participants without sound in the cave. The blue line and dots represent the movement of a singular participant.

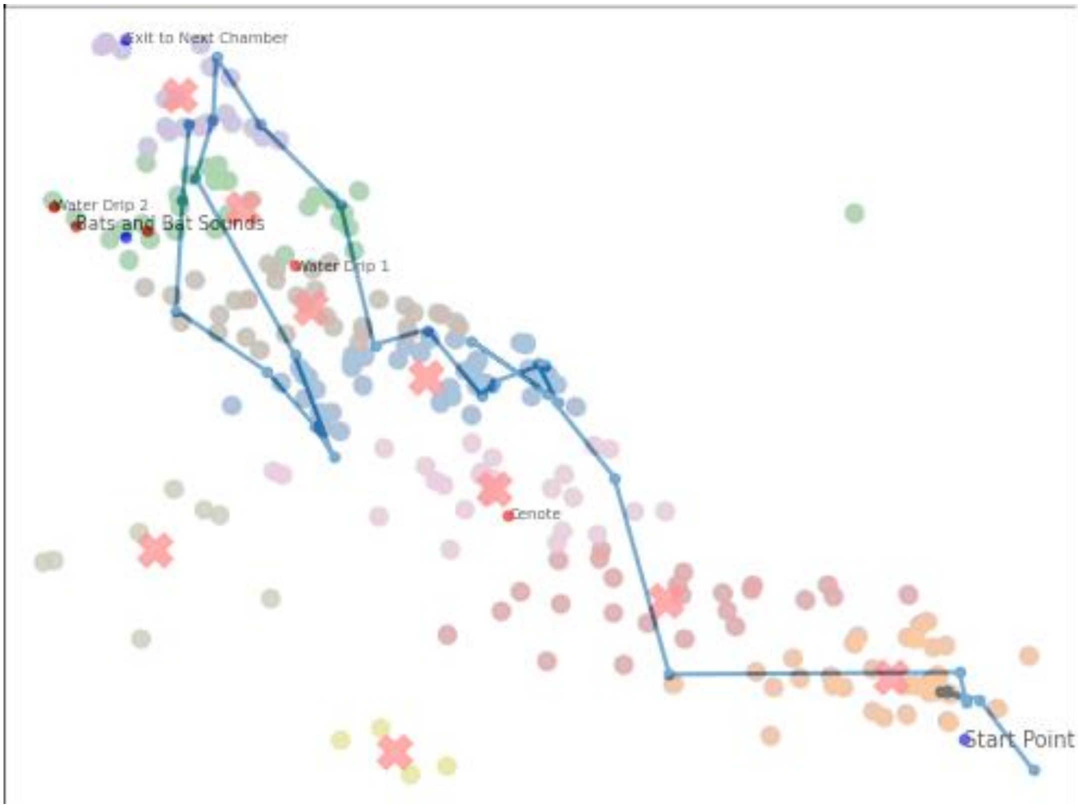


Fig. 8. An overlay of the sample movement from a single participant and the location of landmarks in relation to clusters and cluster centers of participants with sound in the cave.

Discussion

Although the results were too low to achieve statistical significance. One result that stood out strongly from the memory test was that 7 of the participants with sound had the false memory that there was rock art in the experience. It is not entirely clear why this discrepancy exists. It may be due to the participants assuming that there had to be rock art somewhere in the cave, even if they were unsure of the location. There was no consistency in where they marked the rock art, suggesting that there was not any one location or feature that was potentially mistaken as rock art. Alternatively, this result may be due to the textured nature of the cave walls that may have been perceived as rock art in some places. Both groups of participants incorrectly marked the location of dripping water. When evaluating the sound group, many of the participants marked the location of the dripping water *where* the sound of dripping water could be heard but not at the actual location of the dripping water where could also be seen. Two more participants in the sound group attempted to identify the location of the bats on the map, and twice as many also correctly identified where the bats could be found. This is likely due to the presence of sound. Without the presence of sound, participants may not feel the need to look up and around for bats.

The results primarily focus on the results that showed statistical significance with the survey results. The remainder of the results can be found in the appendices. Results that were not significant showed minimal difference for the most part, but at the very least they showed that participants enjoyed the experience overall. This is consistent with other studies of immersive VR and culture heritage. Participants surveyed by Tost and Economou (2009) consistently found that VR offered a feeling of experiencing the past, which made it better to them than text. These results that were significant suggest that the presence of sound contributed to a more immersive and engaging VR experience. Particularly since participants with sound felt more strongly separated from the real world. Overall, sound enhances the experience by grabbing the participants attention. Especially since time passed more quickly and participants were more likely to lose track of time when sound was present. The biggest difference in mean was identified in the question "To what extent did the cave feel alive?". This could be because the cave felt more alive due to the sound of bats and dripping water creating the sense of a living ecosystem.

In addition to a t-test conducted on the survey data. A t-test was also run on the minimum and mean distance from certain landmarks in the VR experience. Only the flying bats and bat audio 3 showed significance for the minimum distance from the landmark. As a whole though the sound participants tended to move closer both with the minimum and mean to the various landmarks in the cave.

The k-means results showed that the center of each cluster of player movement was near to a landmark. In addition, each of these clusters were the larger, more concentrated one relative to the clusters without a landmark situated near their center. This suggests that the presence of sounds as well as environmental features such as water drew the attention of users and directed their movement towards certain parts of the cave.

Chapter 6: Conclusion

Addressing Critiques of Phenomenology

The digital approach to phenomenology taken in this dissertation successfully addresses many of the critique directed towards phenomenological archaeology. By avoiding a single person's perspective, VR allows to pool experiences of a space from participants who are ignorant of our research hypothesis. Rather than the lone archaeologist traversing the landscape, multiple participants all engage with the same controlled experience. In VR environment variables are controlled and therefore each person is experiencing the same thing. Even if how they engage with that experience differs. Collecting data on the experience of multiple participants also challenges critiques of phenomenological archaeology on the grounds of evidential rigor. While a participants experience of the VR environment is subjective. The data collected from their experience is not. Whether that be a post-experience survey or the logging of player movement. Phenomenological archaeology claims that traditional fieldwork is Cartesian and Sterile, and it aims to challenge Cartesians frameworks in archaeology. Critiques of phenomenological archaeology like Fleming (2006) argued that Cartesian frameworks are unavoidable in archaeology, and even Tilley (1994) used a camcorder and 2D images. A digital approach to phenomenology finds a healthy middle ground between these two sides. Experience is considered within the Cartesian framework of a virtual reconstruction of an archaeological site. However, this experience is not a 2D image or video, rather it is an immersive experience in which the participant has agency and freedom of movement.

Creating a VR Experience

The post experience survey t-test did not demonstrate a significant difference between the means of the groups with sound and no sound. Player movement k-means results showed some clustering indicating some portioning, however the overall results were promising but inconclusive. Nonetheless, the overall results remain promising with strong indications that a larger sample size combined with greater computer processing for improved visual fidelity would be beneficial. Overall, results were primarily in the direction we expected, the images were suggestive an immersive experience, and the experiment worked. As a proof of concept, success was attained and this bodes well for applications in digital conservation of sites and the sounds within that can be shared with both colleagues, students of archaeology, and the public. There is great potential for incorporation of the demonstrated technology and technique for museum exhibits and conservation of landscapes, caves, and ancient places. Future applications appear very promising.

Survey results and comments from students demonstrate that participants in both groups greatly enjoyed the VR experience and, in some cases, became captivated by the virtual world they found themselves in. Minimally, they explored what was previously an unknown world while at the same time come away with new knowledge and questions. This is itself but one important result of the experiment. The promise of VR as a deliverable in the representation of archaeological landscapes is greatly enhanced by sound, even with the relatively small sample size employed in the experiment, indicated that sound helps improve such a representation, in this case a cave that likely would never be seen or appreciated by the students otherwise.

Building on the Experiment

The results of the experiment, one part of this dissertation, were both promising and suggest the need for further investigation. Any future research would require several changes to build upon the existing work. First and foremost is increasing the overall sample size. Thirty students potentially a relatively low sample size, and the number of students participating in the memory was far too low. Though this was due to starting the memory test after the experiment had already begun A larger sample size would allow for a more robust and measure of the experiential design and results, and make it clear if the current sample size is sufficient for detecting meaningful differences between the participant groups. A larger area for the participants to move through is desirable to provide for (1) the collection of more player locational data; (2) the addition of more landmarks; (3) a more expansive array and variety of sounds; and (4) the incorporation of additional natural and archaeological features. This would allow more robust analysis and comparison of movement between the “with sound” and ”without sound” groups of participants.

The survey could also be refined for greater depth regarding the questions asked in a variety of ways, including the consideration of physical load and mental workload, particularly if the immersive experience is longer. What might be the ideal amount of time for a participant in the classroom vs. a museum exhibit vs. an onsite center at the actual cave site or grounds? Motion sickness is a potential problem and one participant was forced to stop the experiment early due to experiencing this discomfort. While participants were advised about this, it would be helpful to have participants provide more input on their experience and investigate remedies to counter this effect of the VR experience.

Improving Data Collection Through Eye-Tracking

Eye-tracking in any future experiment is one technique that may potentially improve the quality of the data collected. Here, what is visible as an individual walks through the digital environment is recorded and analyzed for visual saliency based on attention directed at specific areas or objects in each scene. A dataset is constructed from a combination of visual saliency maps and images that relate to what is visible in each moment. This could assist in the understanding of how the placement of decorations and objects in a place affect the visual salience of a space (Opitz 2017).

Beyond Sight and Sound

The benefit of incorporating sound and sight into a cohesive VR experience are clear. Due to a variety of considerations and obstacles, several sensory experiences present in caves that were left out of the VR experience. The first is the lack of any odors or smells. Smells are very noticeable in a cave though it is sometimes dominated by acrid bat guano. While the sample of users did not comment on the absence of these smells, the presence of odors found in the cave would contribute to the overall cave experience and authenticity. The sense of touch also plays a vital role in sensorial experience within a cave. Whether one is crawling over a limestone floor, evading stalagmites or stalactites, picking up a ceramic shard, or coming across bones, cultural artifacts, or fossils, a variety of surfaces and textures are present within a cave. The addition of touch could improve upon the interaction and engagement with the environment in the VR experience. Furthermore, caves are often filled with confined and restricted spaces. VR cannot adequately convey the cramped nature of moving one’s body through narrow passageways and crawlspaces. Finally, the extremely high humidity in the cave cannot currently be captured in the virtual cave. Physically exerting oneself in such conditions is a unique experience not easily replicated. A more confined space or spaces within a museum exhibit could be set up with areas of higher humidity, dampness, and smells.

WAVEs and CAVES

Repeating the experiment in a in more immersive environments such as a Cave, Automatic, Virtual, Environment (CAVE) would allow for greater freedom of movement and may provide an improved method for evaluating what features are important to participants (Defanti et all 2011). Equally, performing similar experiments on sound within an immersive environment such as a CAVE could yield greater clarity and a better understanding of human behavior within specific spaces. VR environments such as a CAVE provide a unique and embodied experience that can handle a variety of data types ranging from point clouds to polygonal models (Knabb et al 2014). CAVES display a variety of datasets, enable clear and easily understood dissemination of data, and allow researchers to reexamine finds at various scales. VR environments are also heuristic tools enabling one to investigate the relationships between artifacts, features, and other aspects of the environment.

Another option would be to make use of the University of California, Merced Wide Area Visualization Environment Center or WAVE. This multi-panel VR environment integrates information from various sources to produce new knowledge about cultural heritage and past phenomenology. The reconstruction and corresponding experience to sound from the archaeological record is an emerging field that has shown positive contributions (Goodwin and Richards-Rissetto 2020). Through my initial proof of concept and this dissertation project, such a system is capable of integrating multiple datasets into a immersive environment ideal for demonstration to all students of archaeology.

Lessons Learned and Suggestions for Future VR Projects

The learning curve for becoming proficient in the use of Unreal Engine 5 was time consuming. In the future, a partnership with a skilled game engineer could be most beneficial in creating a robust product for educational and commercial exhibit use. It is apparent from this dissertation project that becoming proficient in the use of the broadest possible range of skills in Unreal was challenging and required a significant investment of time. Choice of the correct game engine is a critical component and need at any level for a successful transfer of the real world to the digital world followed by an enriching and successful immersive VR experience. Otherwise, one risks spending significant amounts of time and energy on learning skills that end up not being relevant to your final product. In the initial phases of creating the VR experience, significant time was invested in learning how to work with point clouds in Unreal Engine 5. Unfortunately, after some time, it became apparent that there were limitations on the level of detail and realism one could achieve with this game engine software, even with a relatively dense point cloud. This meant that the time spent on learning how to manipulate and utilize point clouds may have been better spent on other aspects of the experiment. This experience will contribute to the success of future endeavors in the digital preservation of objects, places, and sites of importance in the field of archaeology and related disciplines.

Fig. 1: The initial point cloud used for the VR experience which was discarded in favor of a more detailed mesh.

Here are several recommendations for meeting additional requirements in a future VR environment. (1) The Soundscape Plugin: enables the procedural generation of sounds as the user moves through the environment. The sound system is managed autonomously and eliminates the need for manual placement of sounds in the environment, saves time and effort, and creates a more dynamic experience; (2) The Synthesis and DSP Effects plugin: allows the creation of impulse responses from sound files. These impulse responses are used in the convolution reverb algorithm to artificially replicate the reverb of an interior space such as a cave. This would create a new level of immersion and engagement with sounds in the VR environment; (3) The Waveform Editor: for the basic editing of imported sound files and eliminates the need to edit them in an outside program then re-import them. Files are trimmable, fade added in, and gain normalized, all critical sound editing functions.

Dissertation Appendices

Pre-Experience Demographic Questions

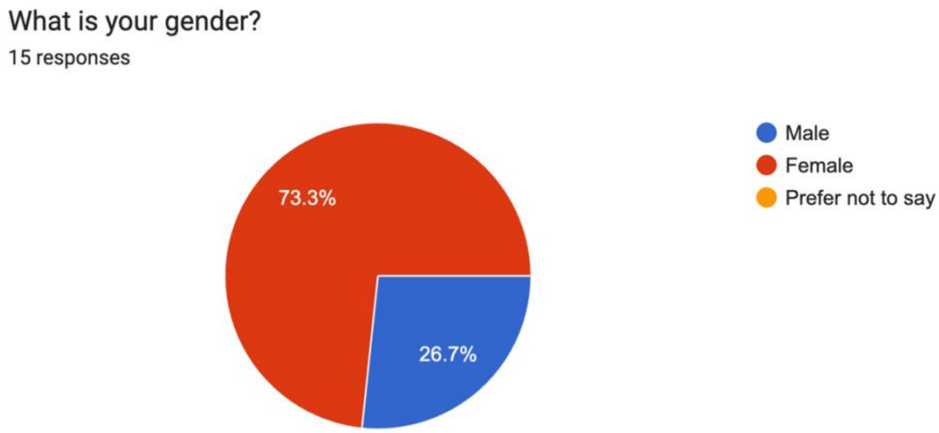


Fig. 1: Participants with sound.

:

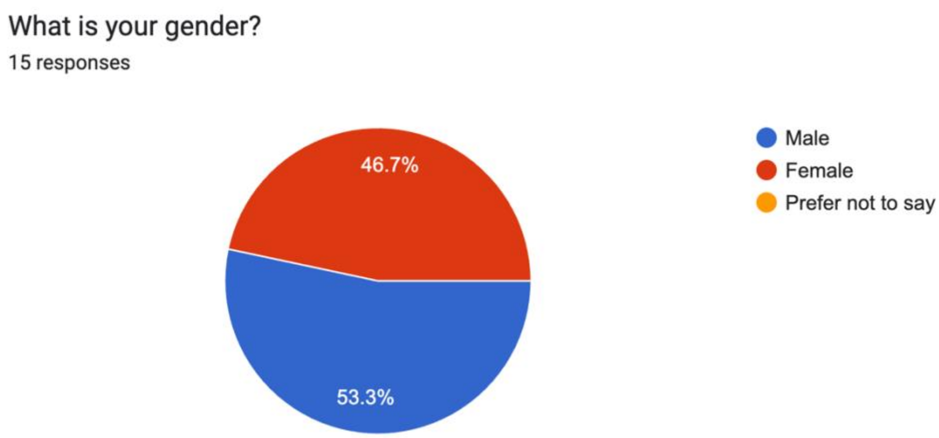


Fig. 2: Participants without sound.

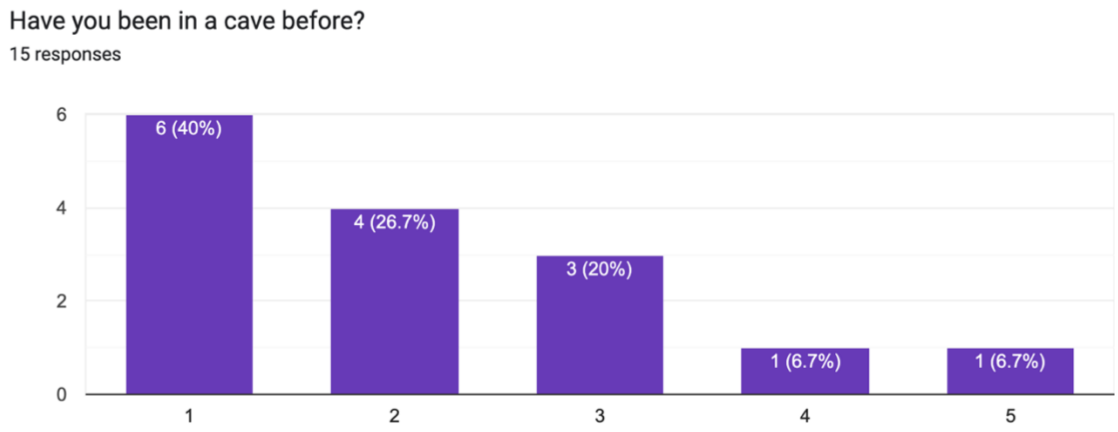


Fig. 3: Participants with sound

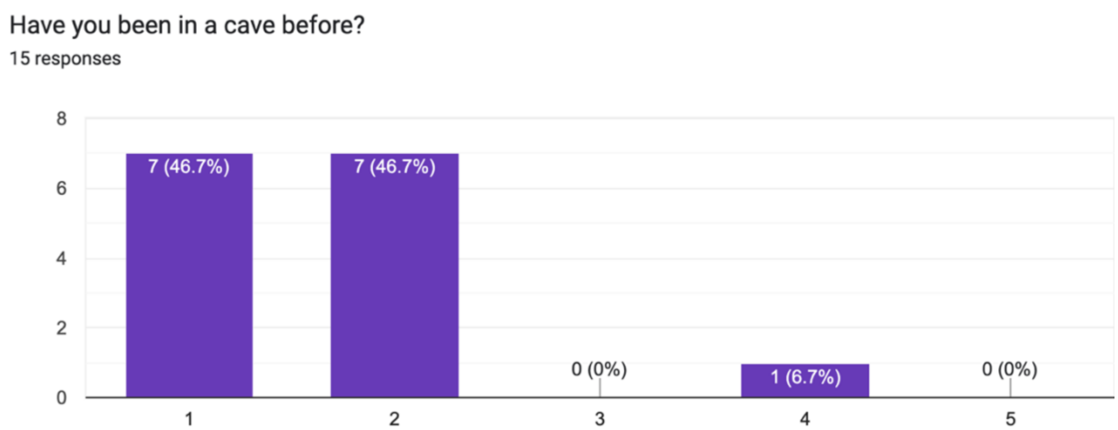


Fig. 4: Participants without sound

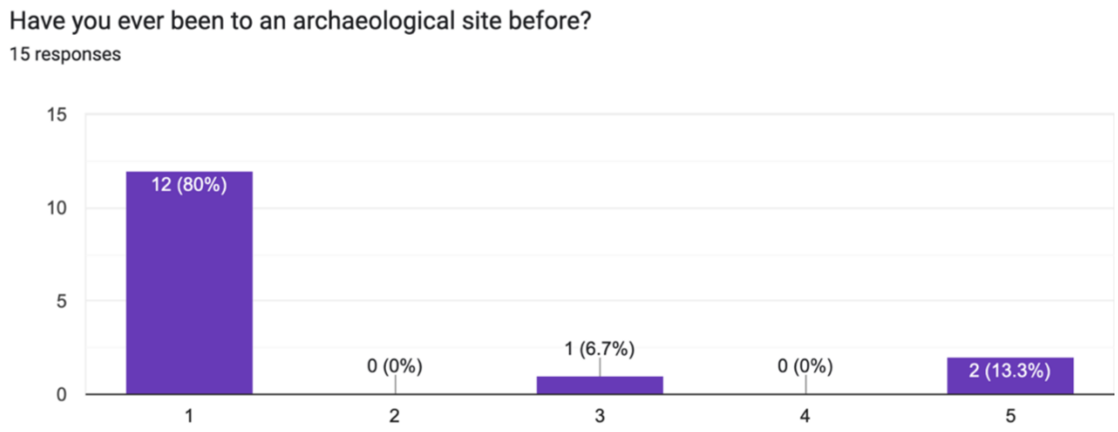


Fig. 5: Participants with sound

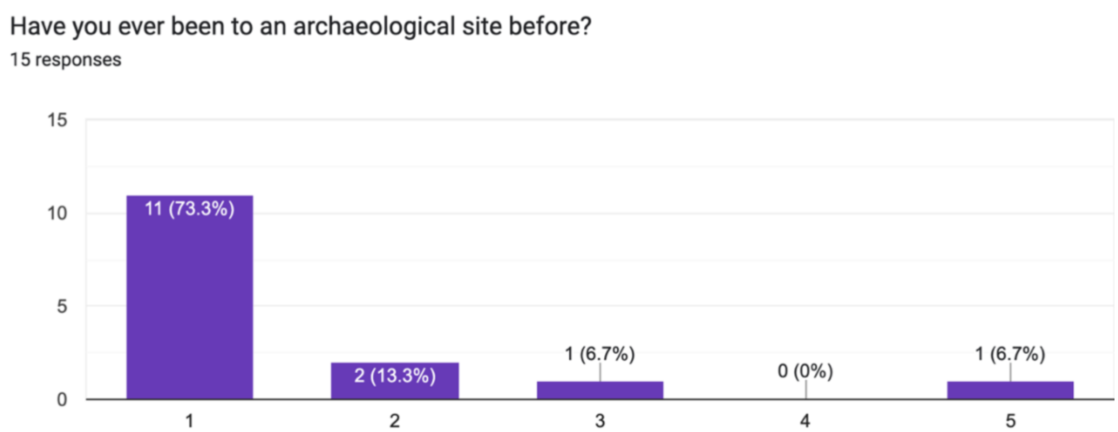


Fig. 6: Participants without sound

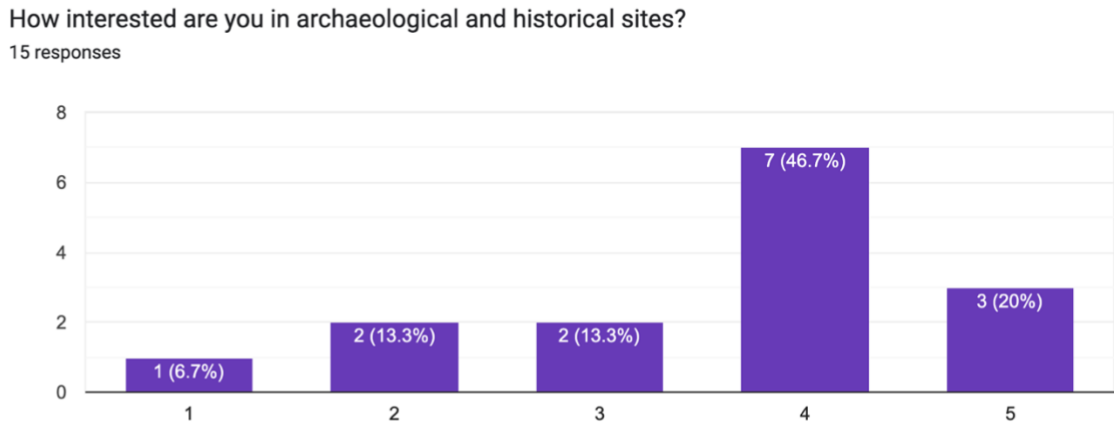


Fig. 7: Participants with sound

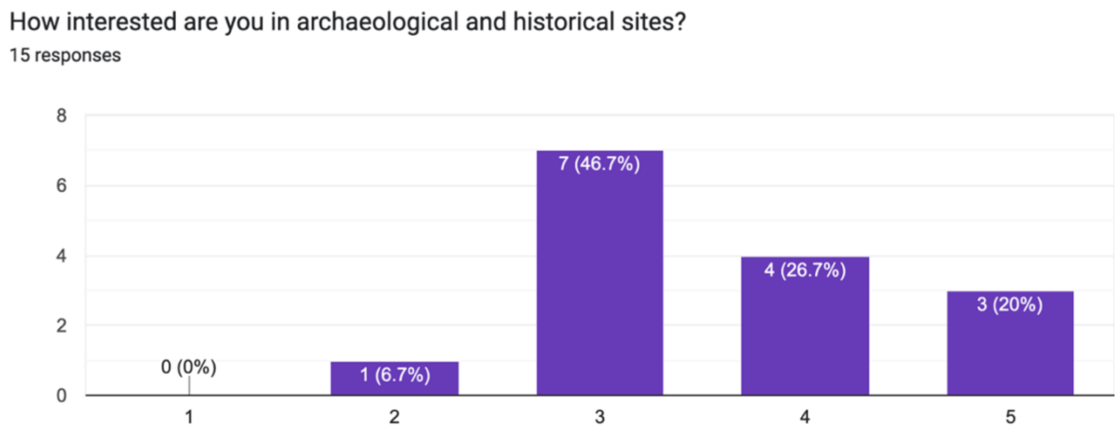


Fig. 8: Participants without sound

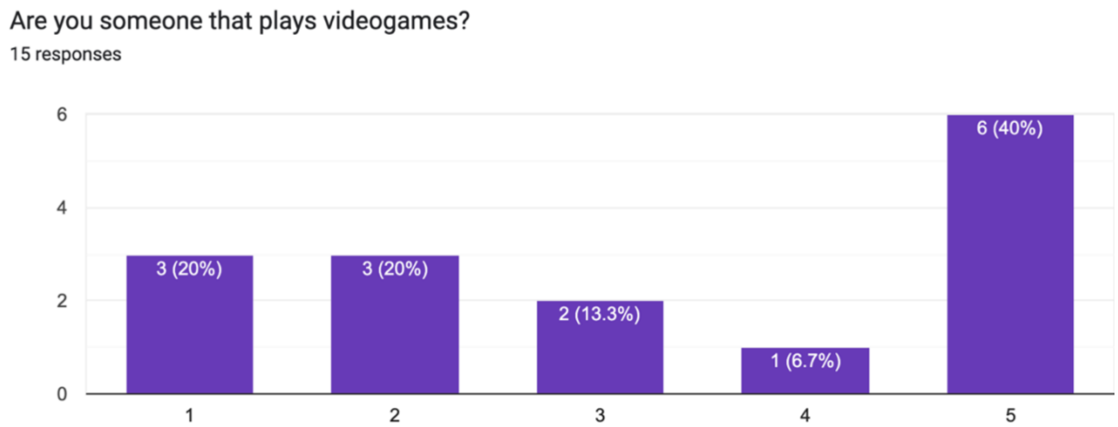


Fig. 9: Participants with sound

:

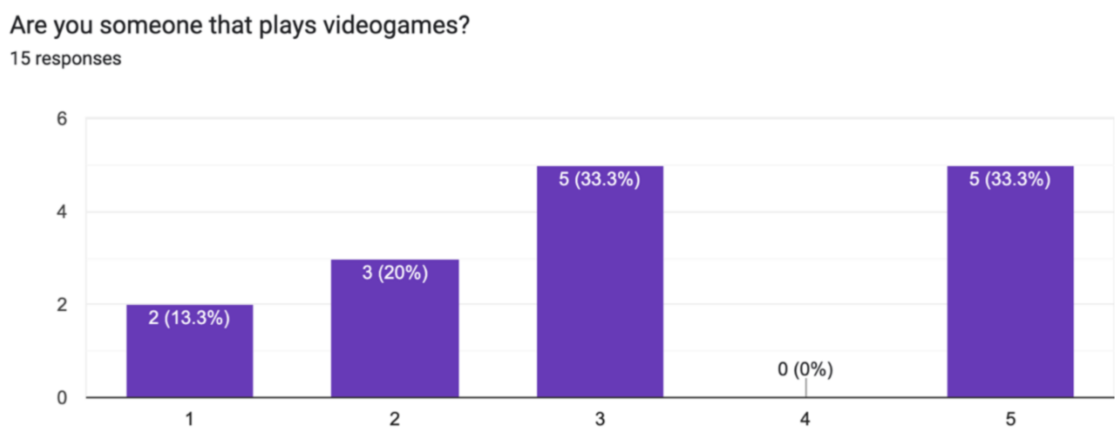


Fig. 10: Participants without sound

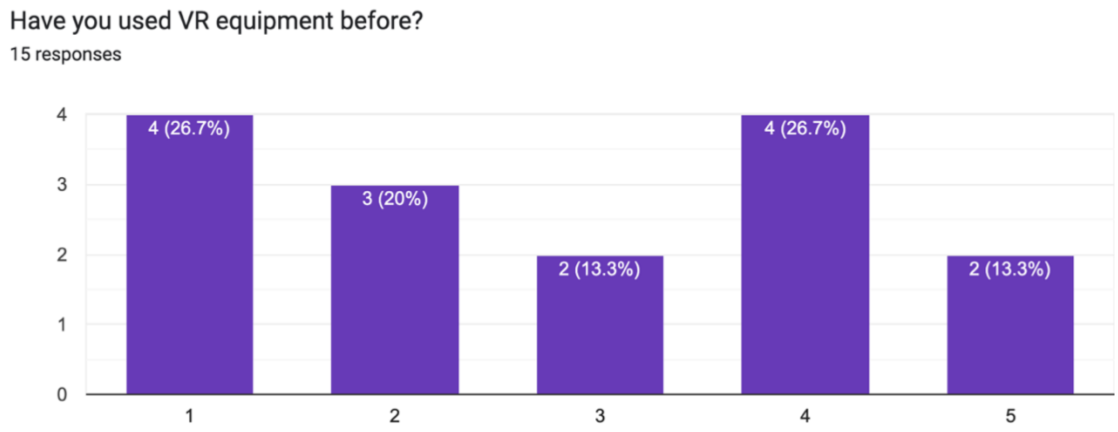


Fig. 11: Participants with sound

:

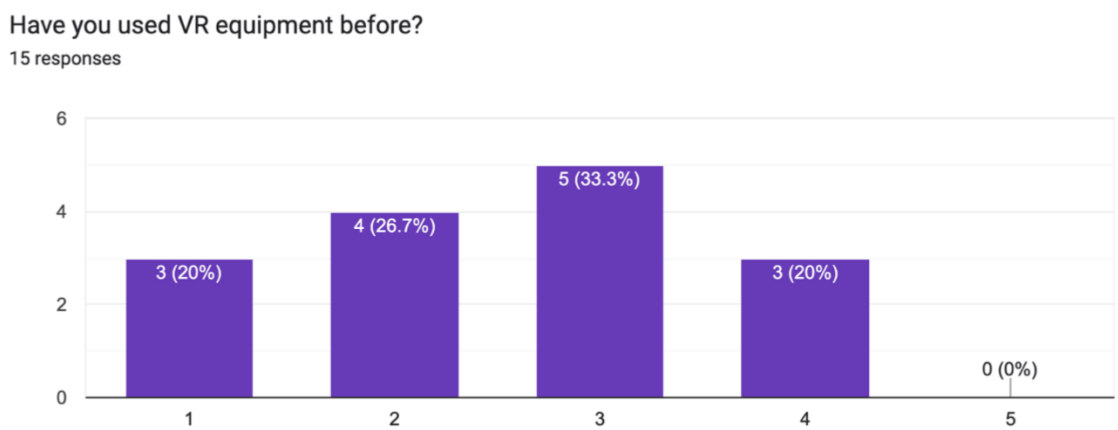


Fig. 12: Participants without sound

Participants with Sound:

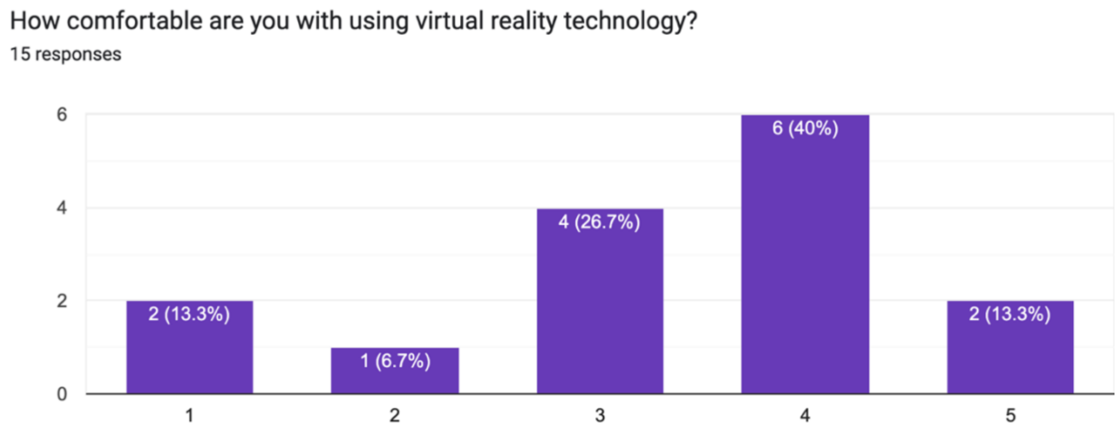


Fig. 13: Participants with sound

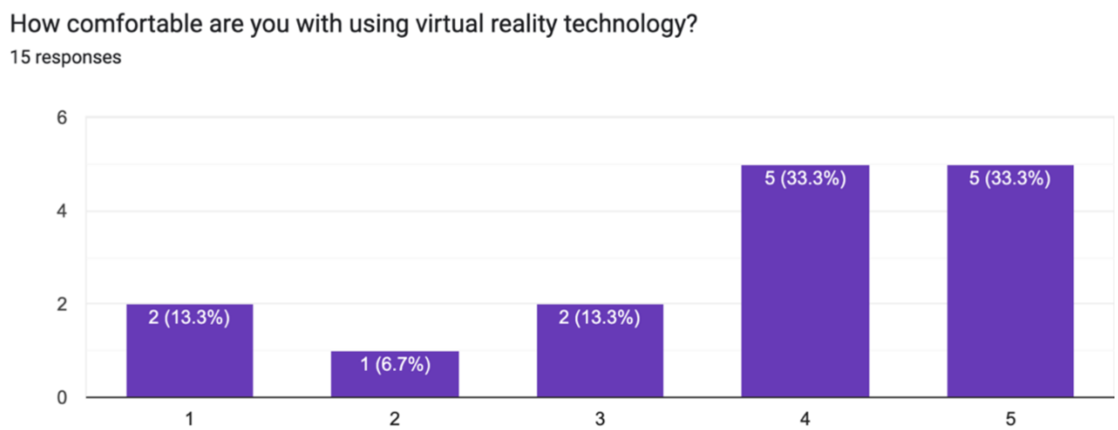
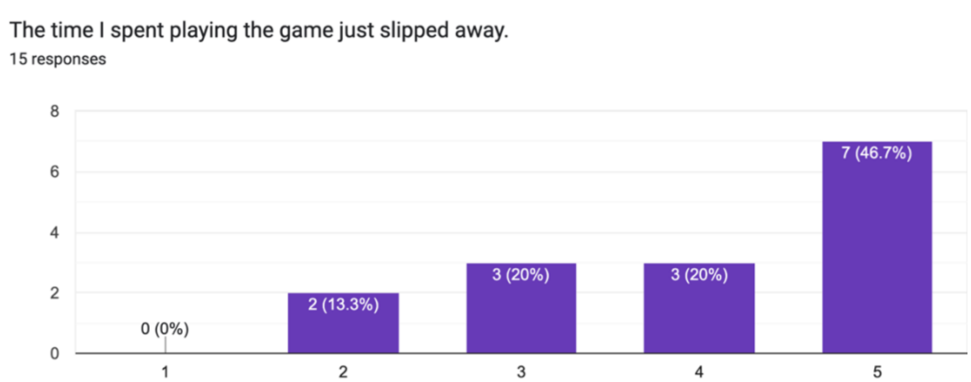


Fig. 14: Participants without sound



.

Fig. 15: Participants with sound.

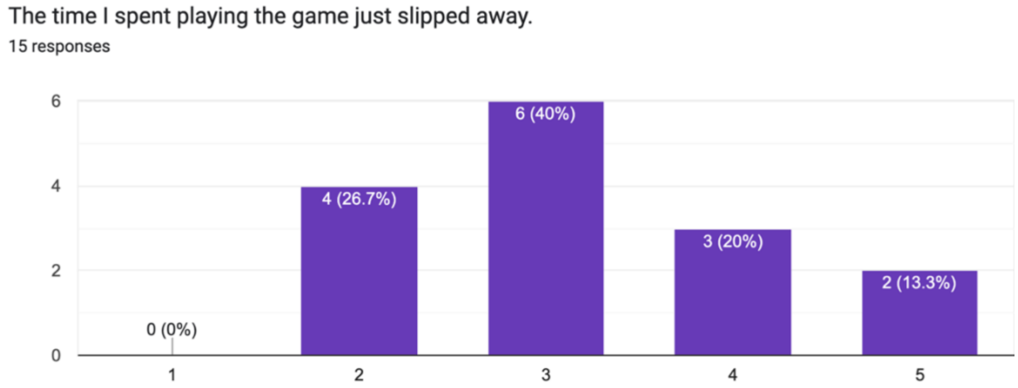


Fig. 16: Participants without sound. The largest concentration of participants with sound leaned towards the higher end. Those participants without sound sorted out mostly in the middle.

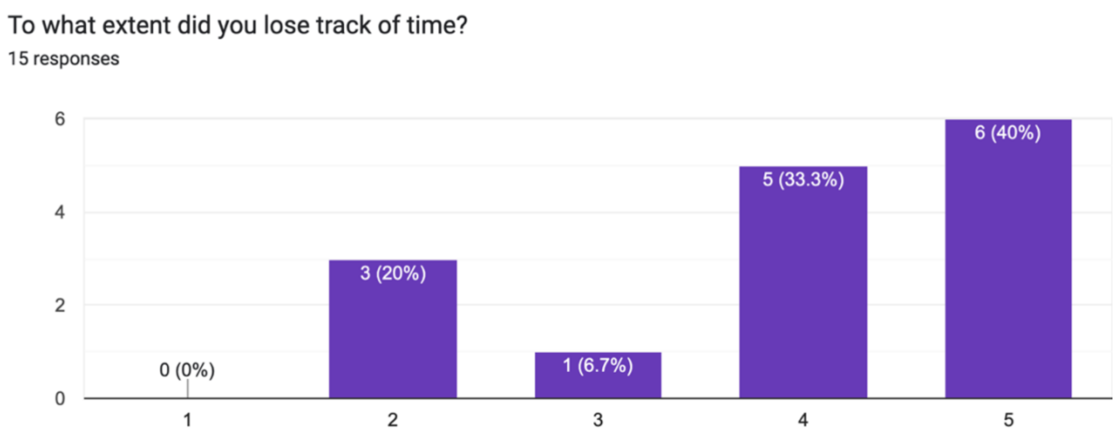


Fig. 17: Participants with sound.

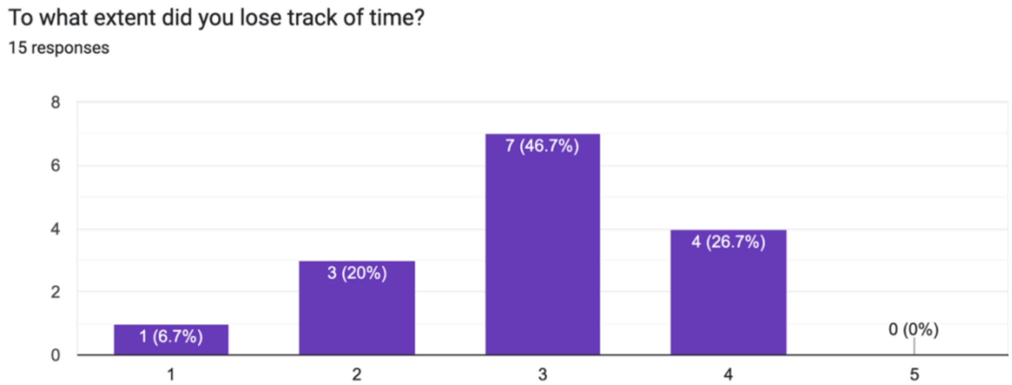


Fig. 18: Participants without sound. Participants with sound appeared to skew towards the higher end of 3, 4 and 5. While participants without sound skewed towards the middle.

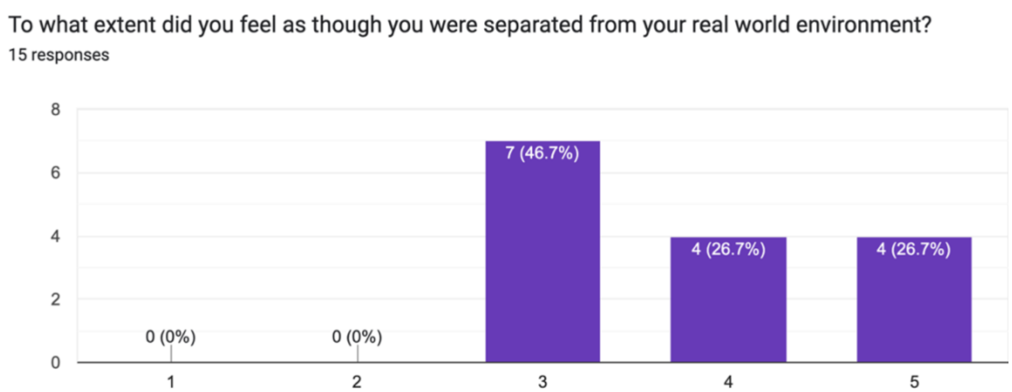


Fig. 19: Participants with sound.

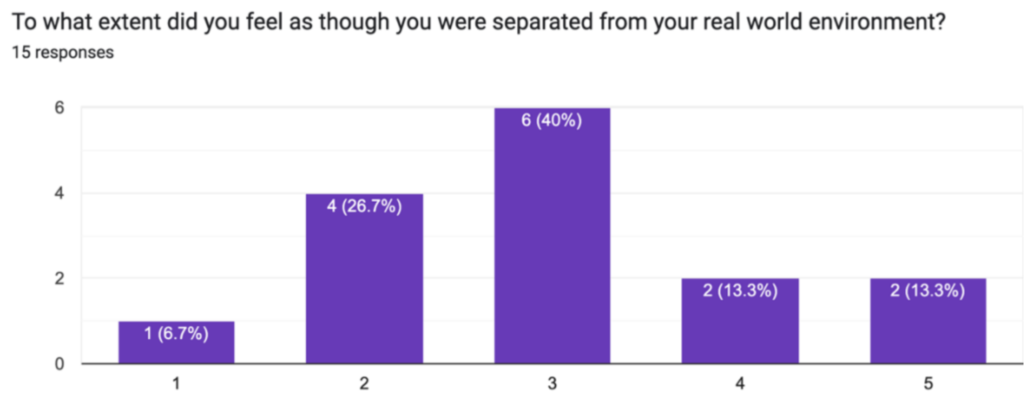


Fig. 20: Participants without sound. Participants with sound fell towards the higher end while the participants without sound were slightly more dispersed, showing a higher concentration in the middle

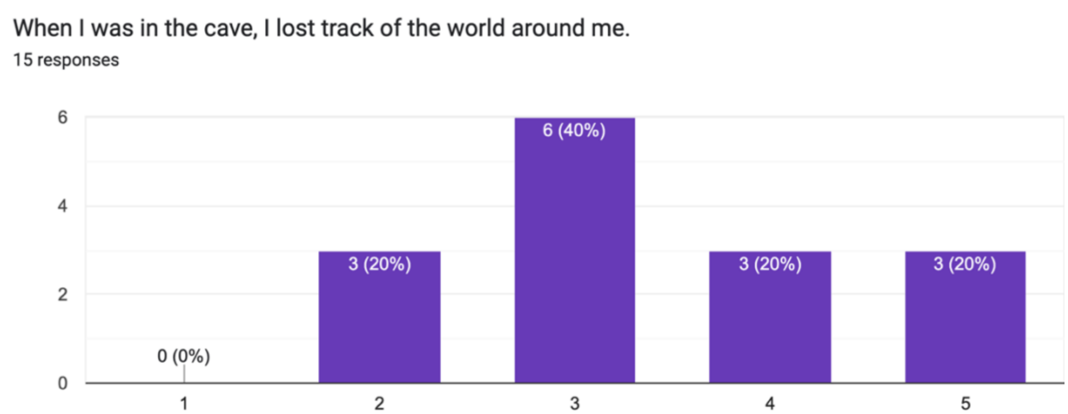


Fig. 21: Participants with sound

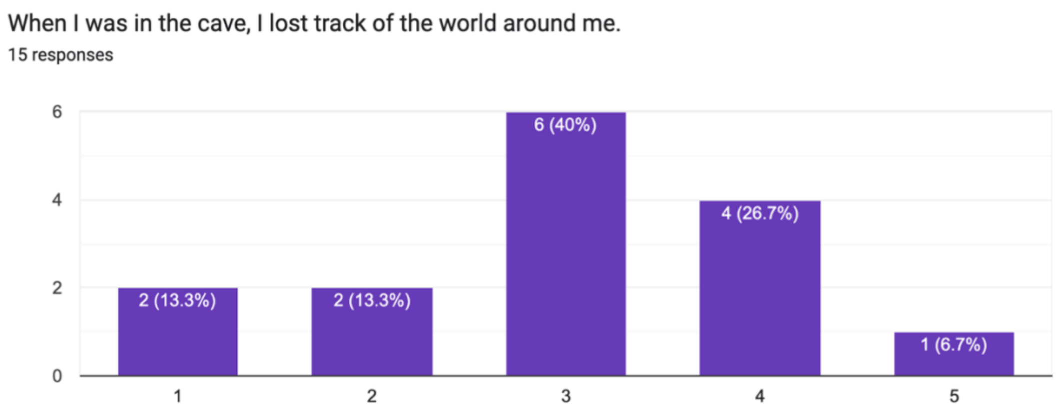


Fig. 22: Participants without sound

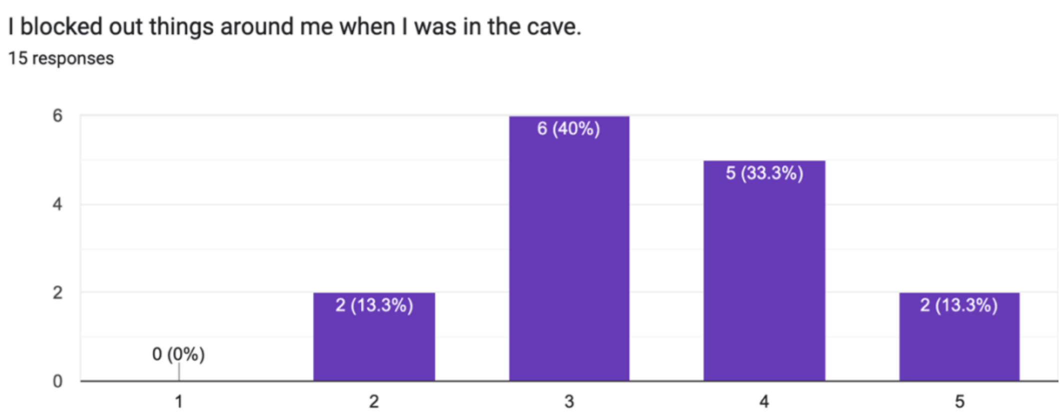


Fig. 23: Participants with sound

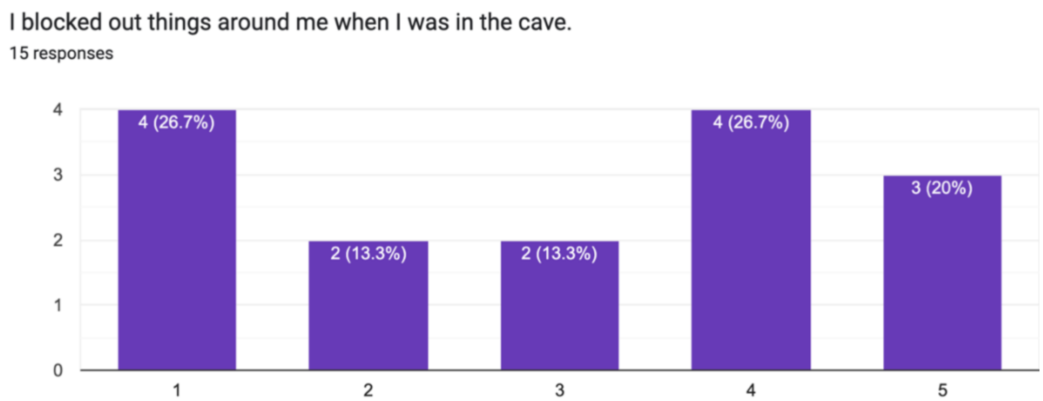


Fig. 24: Participants without sound

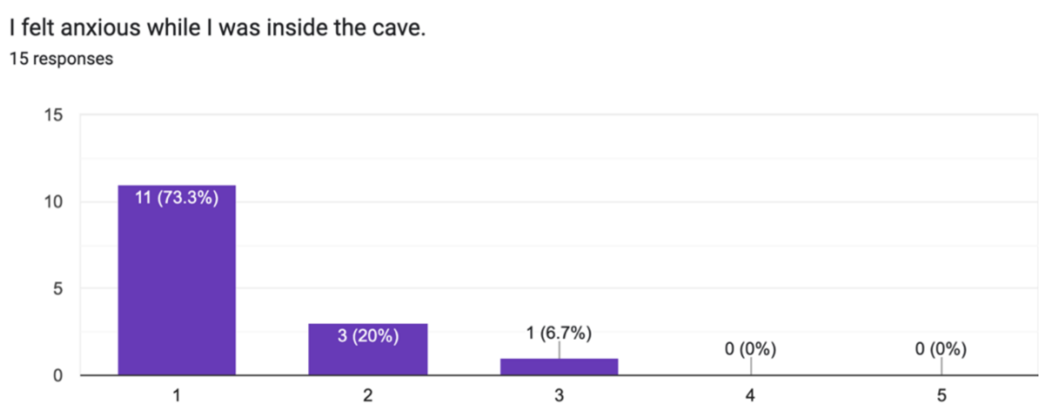


Fig. 25: Participants with sound

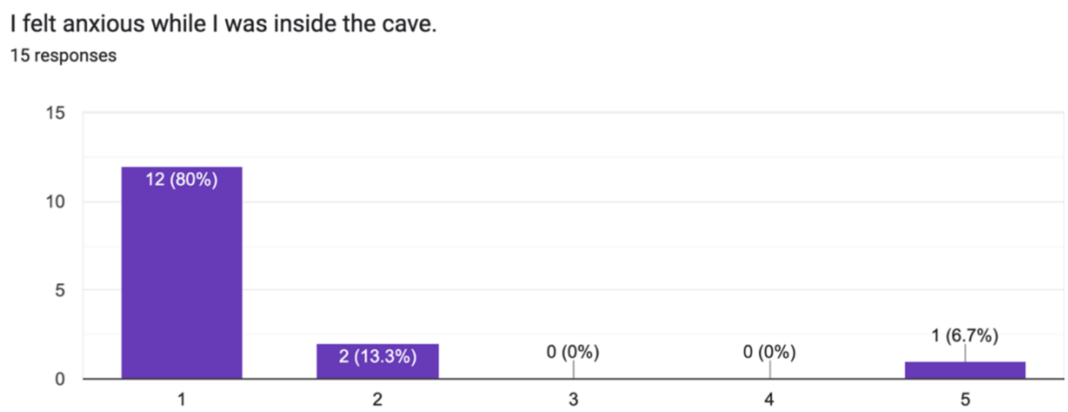


Fig. 26: Participants without sound

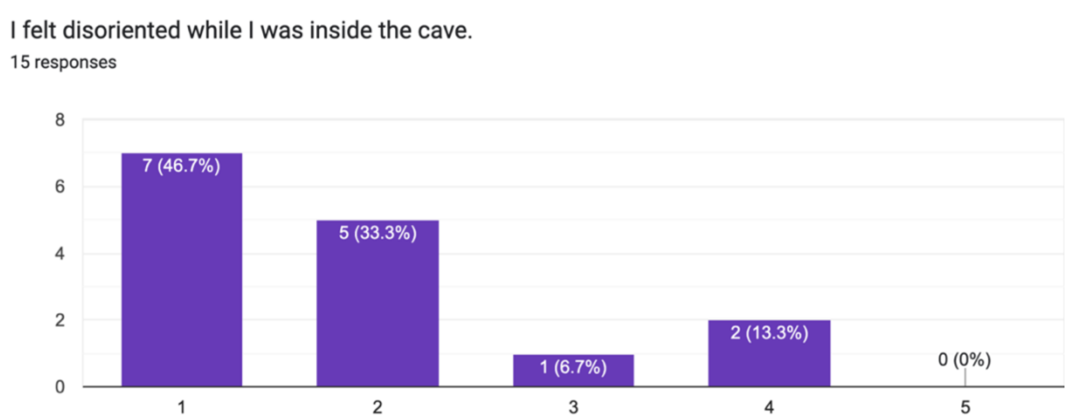


Fig. 27: Participants with sound

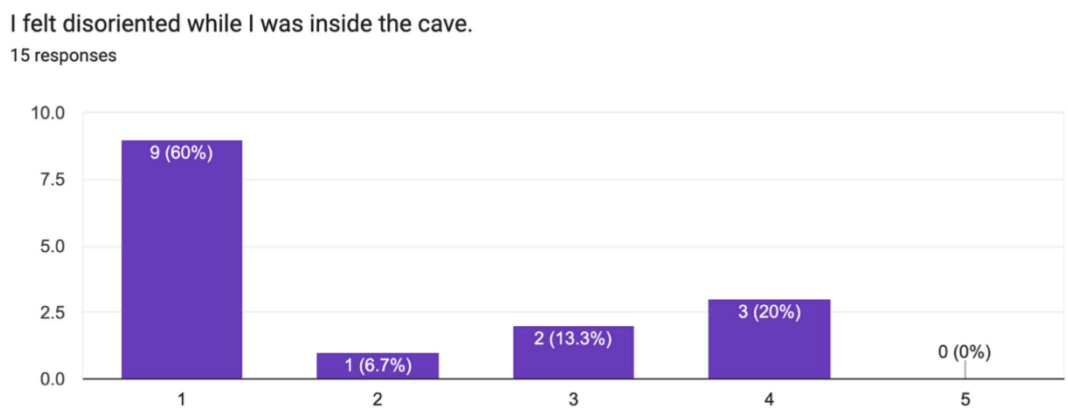


Fig. 28: Participants without sound

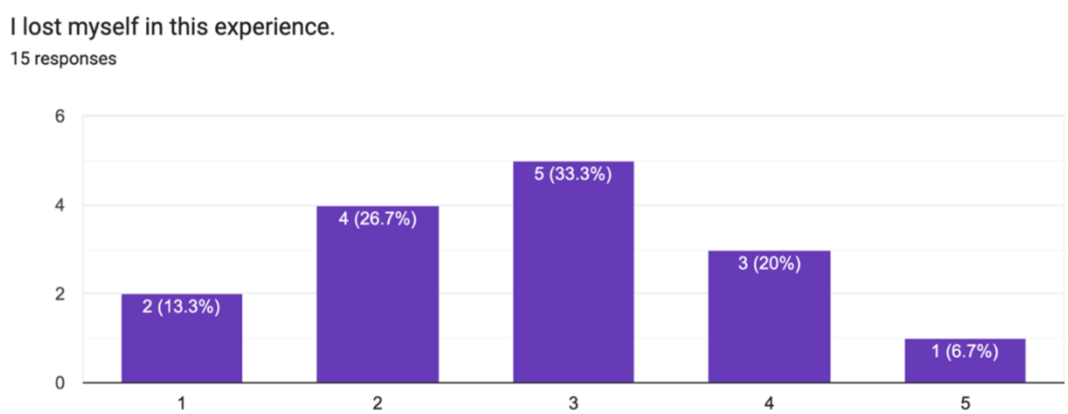


Fig. 29: Participants with sound

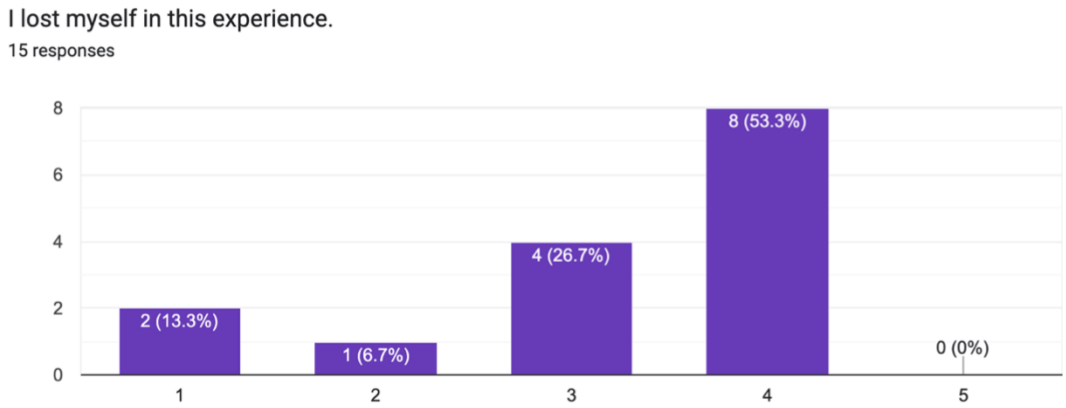


Fig. 30: Participants without sound

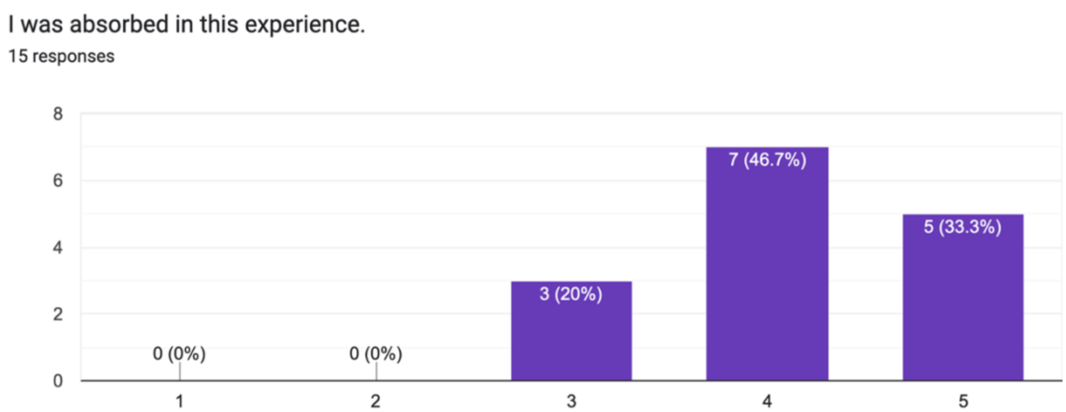


Fig. 31: Participants with sound

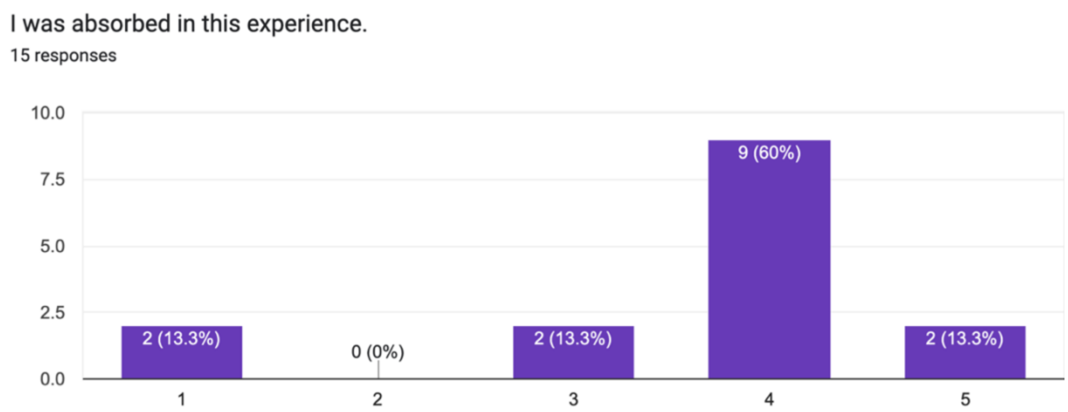


Fig. 32: Participants without sound

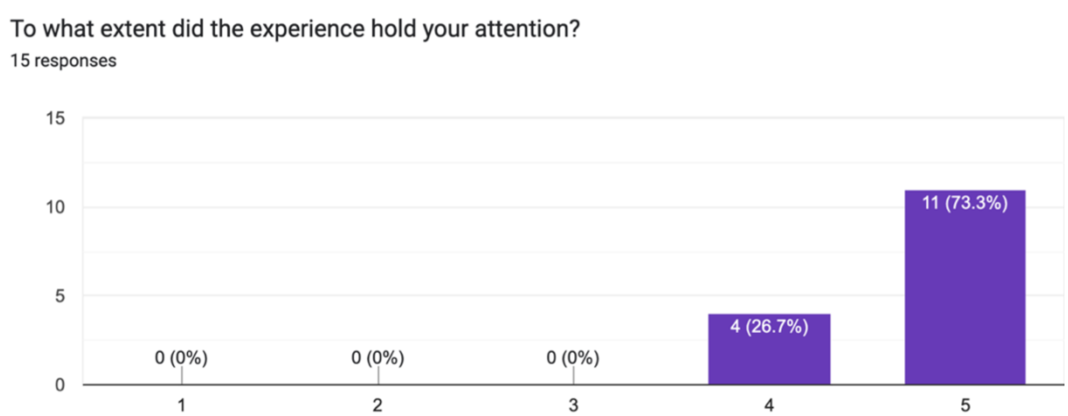


Fig. 33: Participants with sound

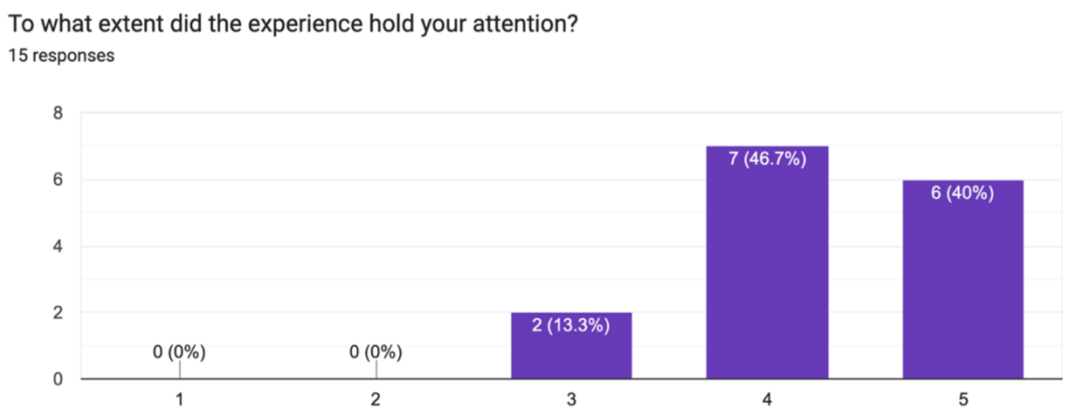


Fig. 34: Participants without sound

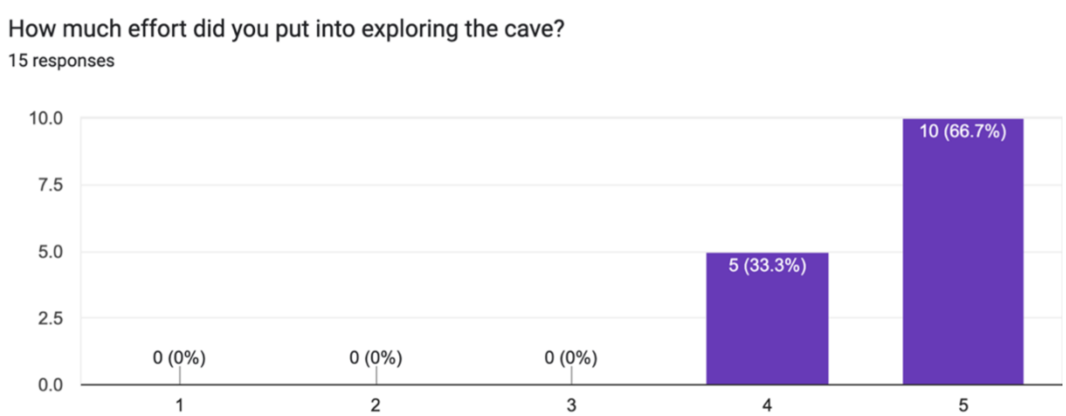


Fig. 35: Participants with sound

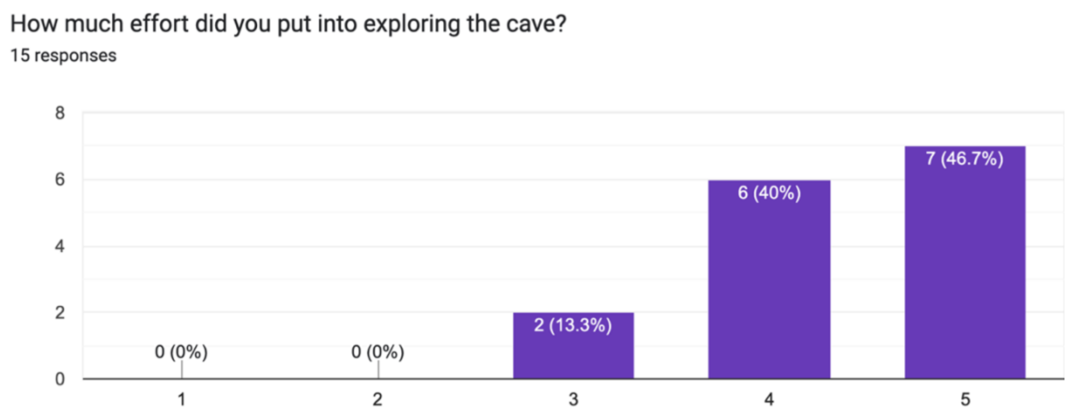


Fig. 36: Participants without sound

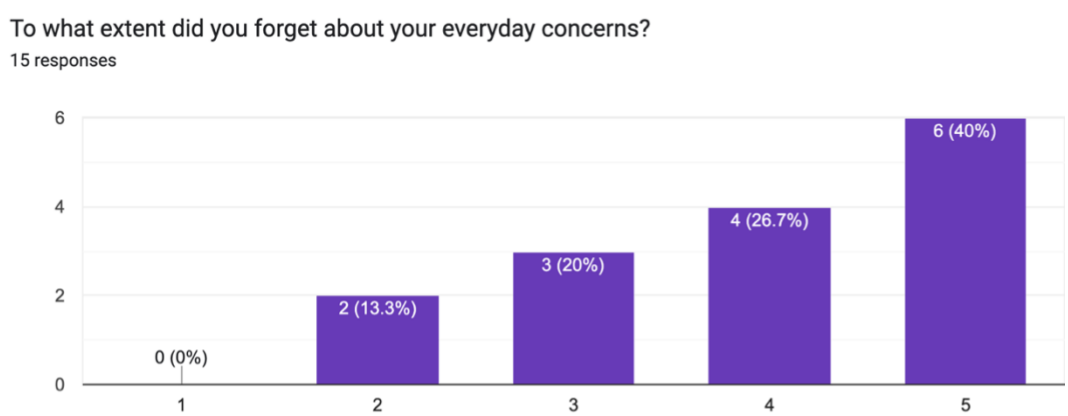


Fig. 37: Participants with sound

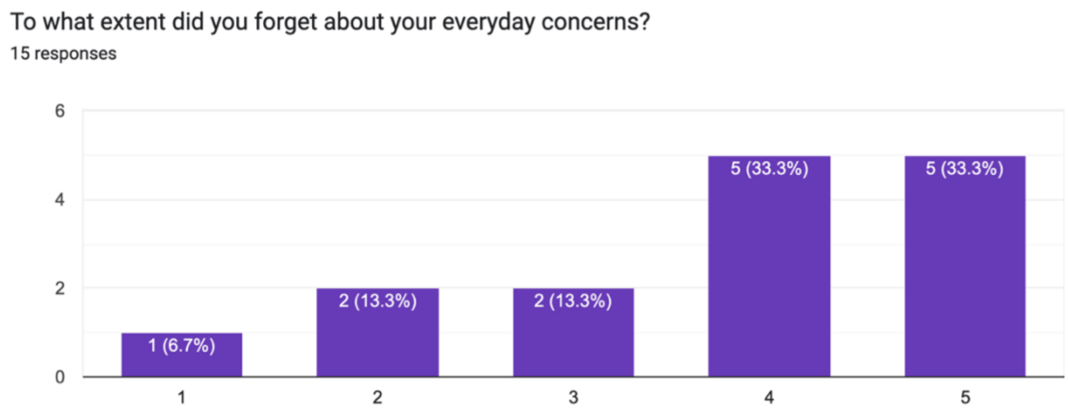


Fig. 38: Participants without sound

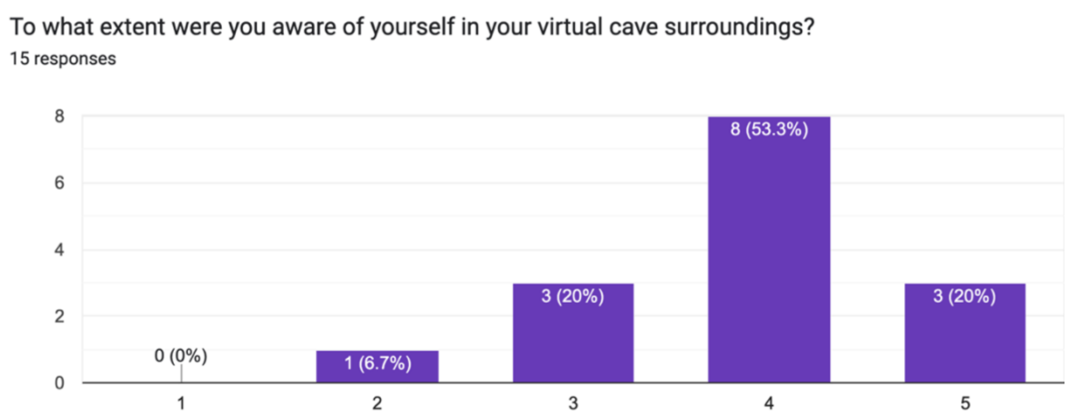


Fig. 39: Participants with sound

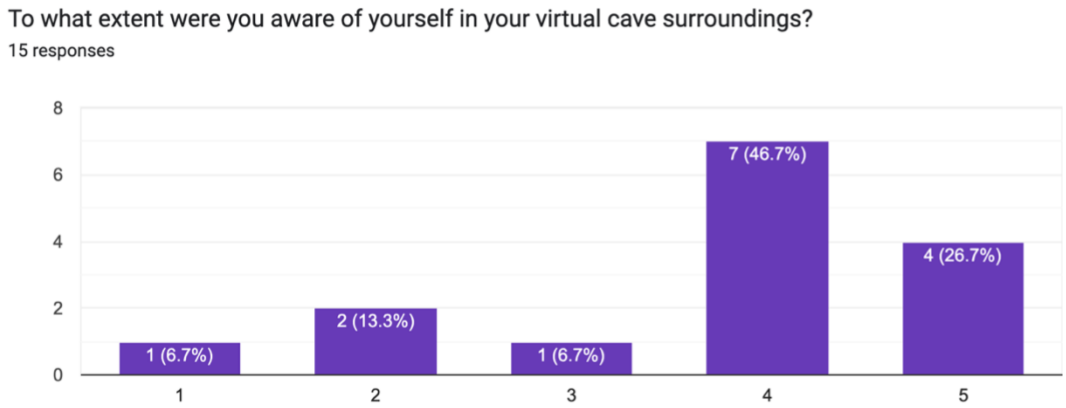


Fig. 40: Participants without sound

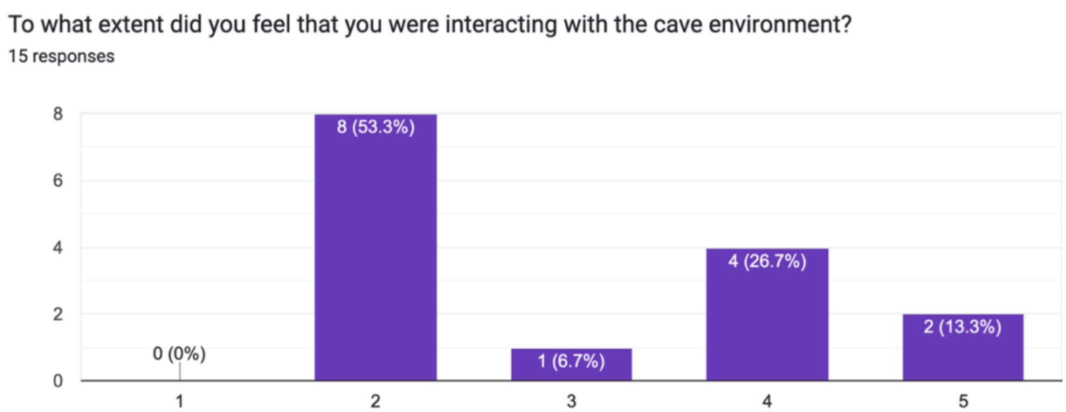


Fig. 41: Participants with sound

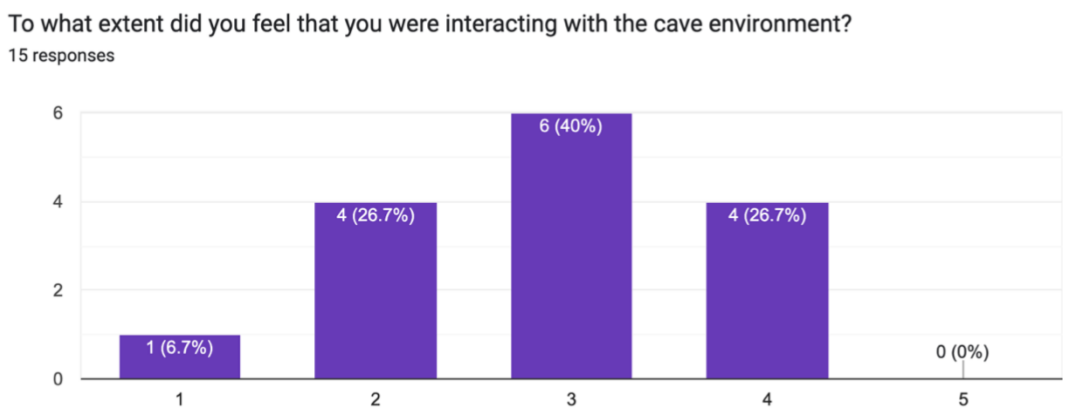


Fig. 42: Participants without sound

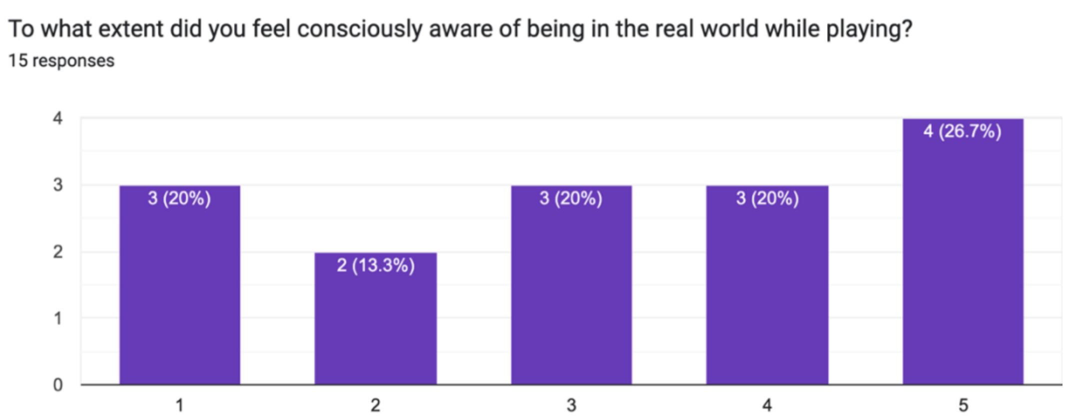


Fig. 43: Participants with sound

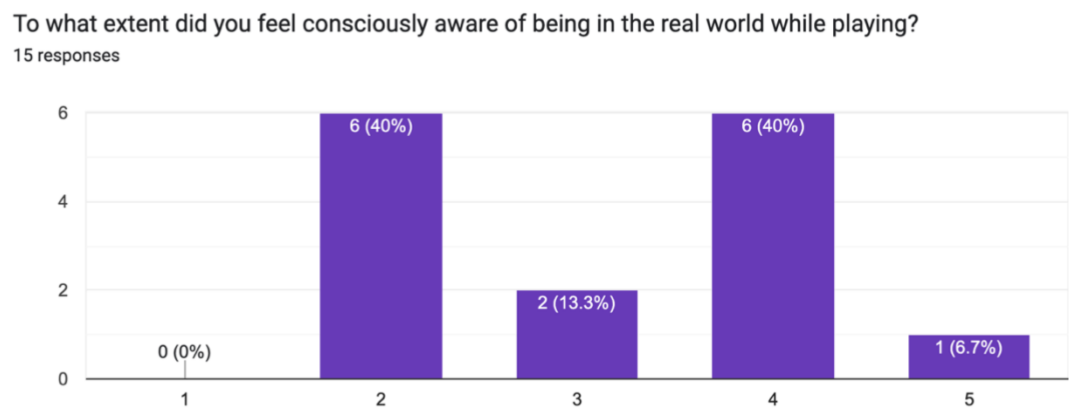


Fig. 44: Participants without sound

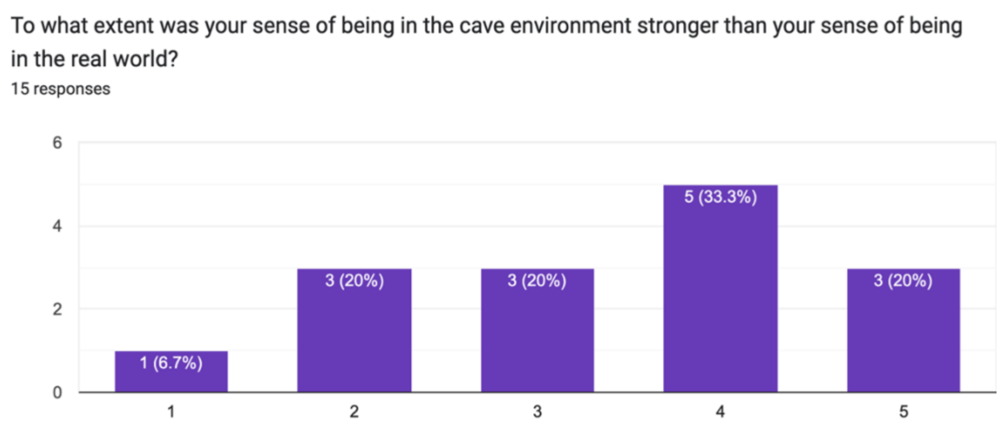


Fig. 45: Participants with sound

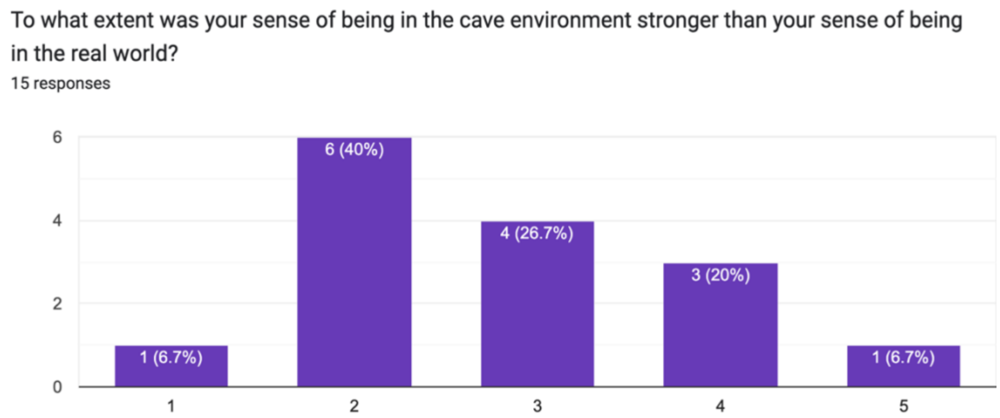


Fig. 46: Participants without sound

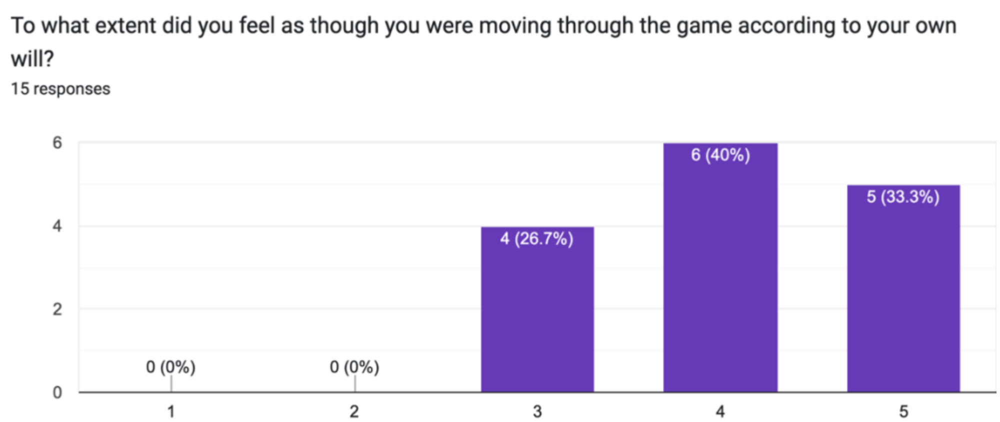


Fig. 47: Participants with sound

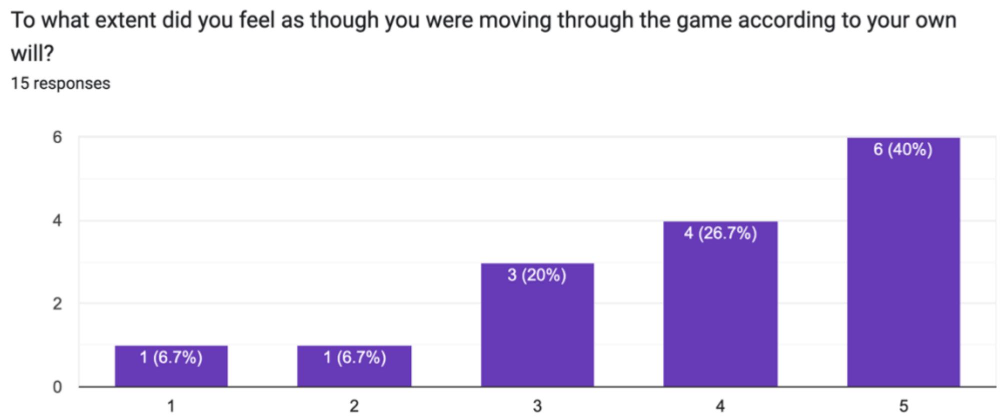


Fig. 48: Participants without sound

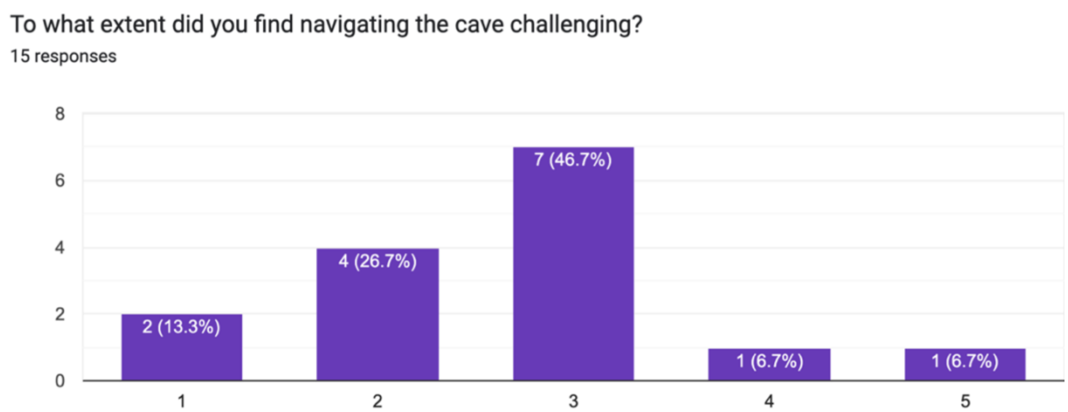


Fig. 49: Participants with sound

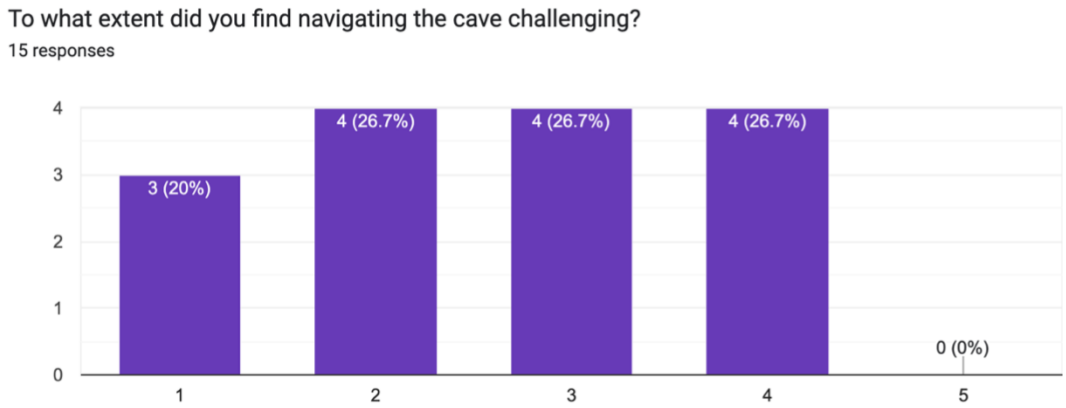


Fig. 50: Participants without sound

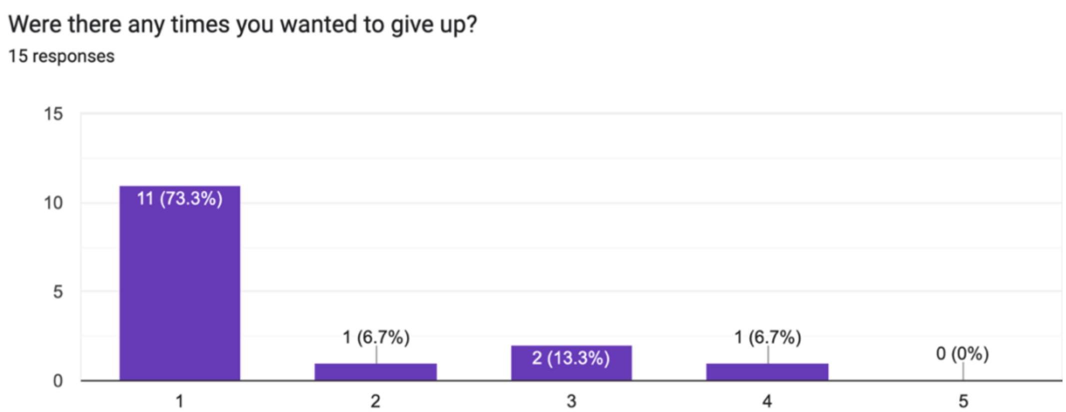


Fig. 51: Participants with sound

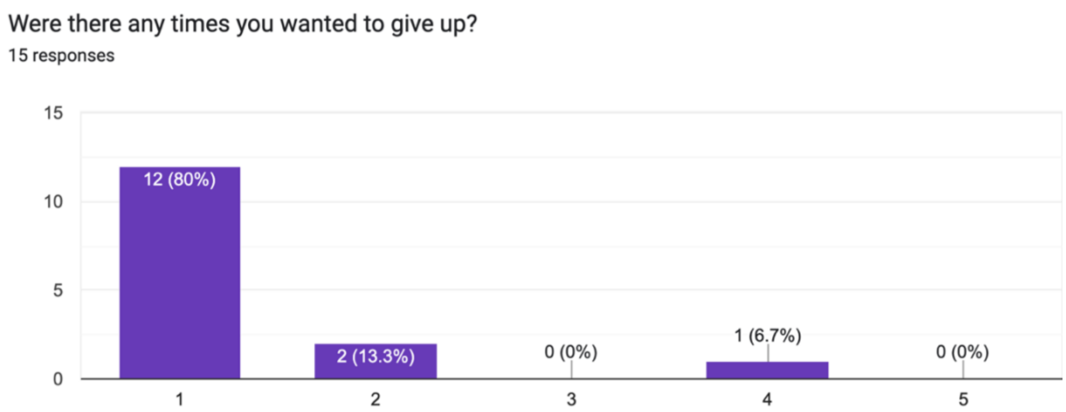


Fig. 52: Participants without sound

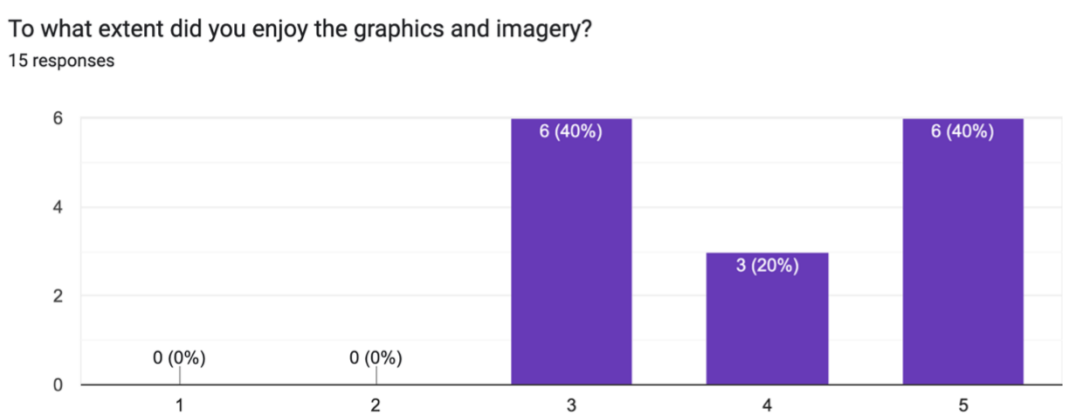


Fig. 53: Participants with sound

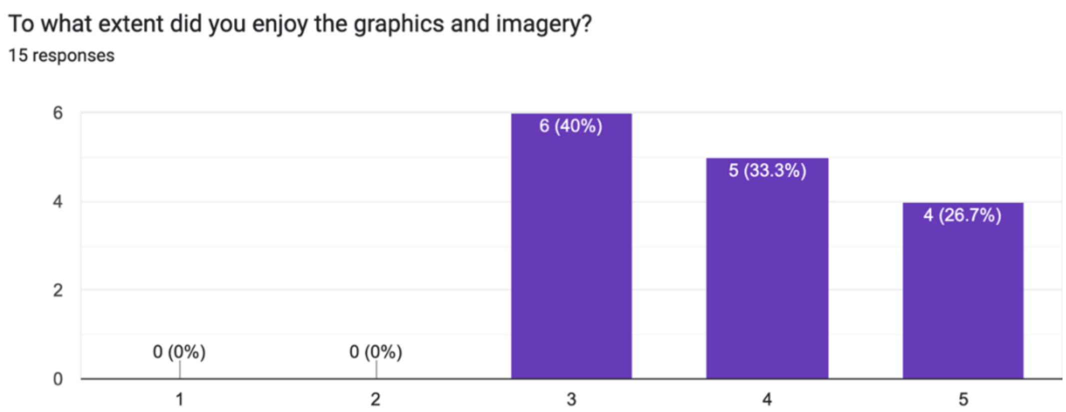


Fig. 54: Participants without sound

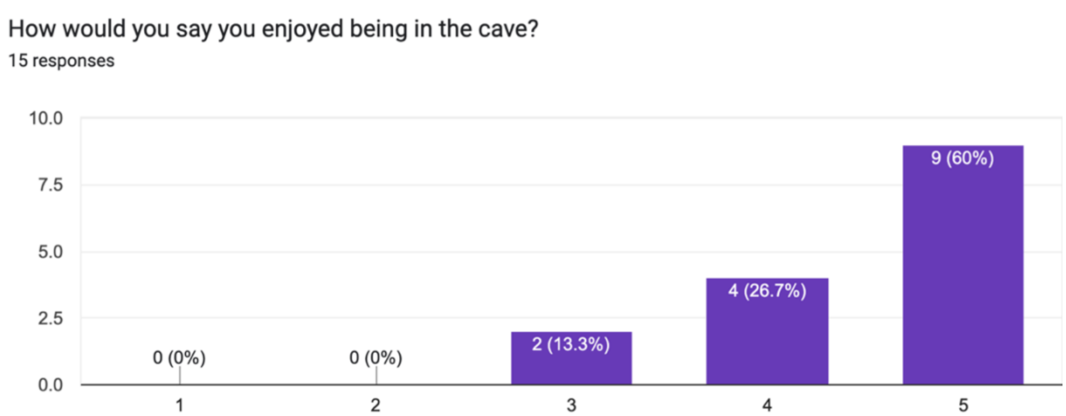


Fig. 55: Participants with sound

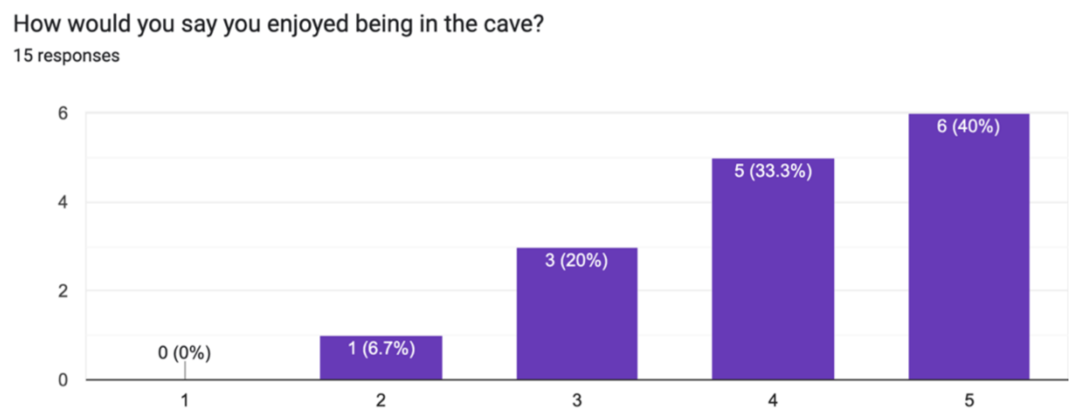


Fig. 56: Participants without sound

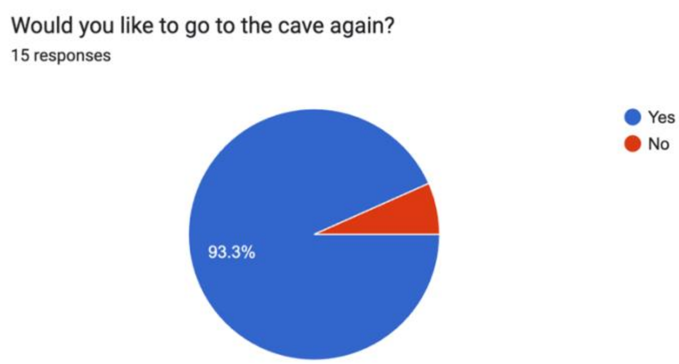


Fig. 57: Participants with sound

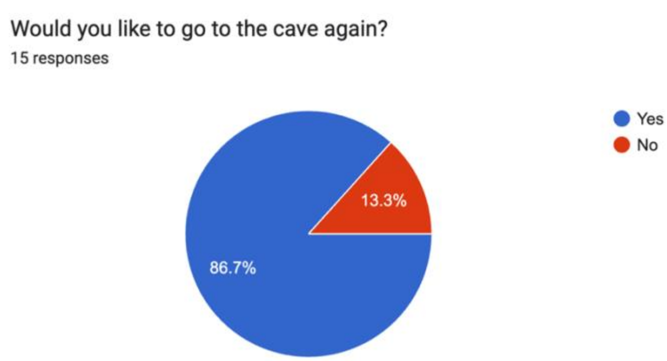


Fig. 58: Participants without sound

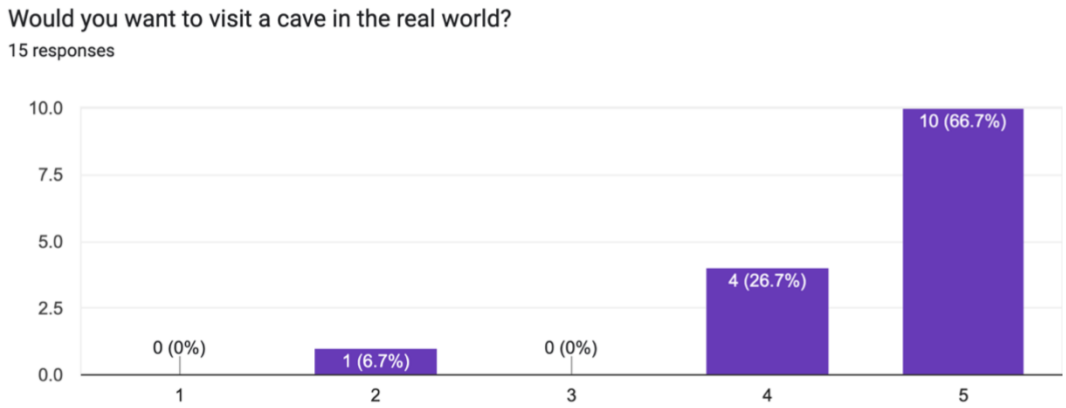


Fig. 59: Participants with sound

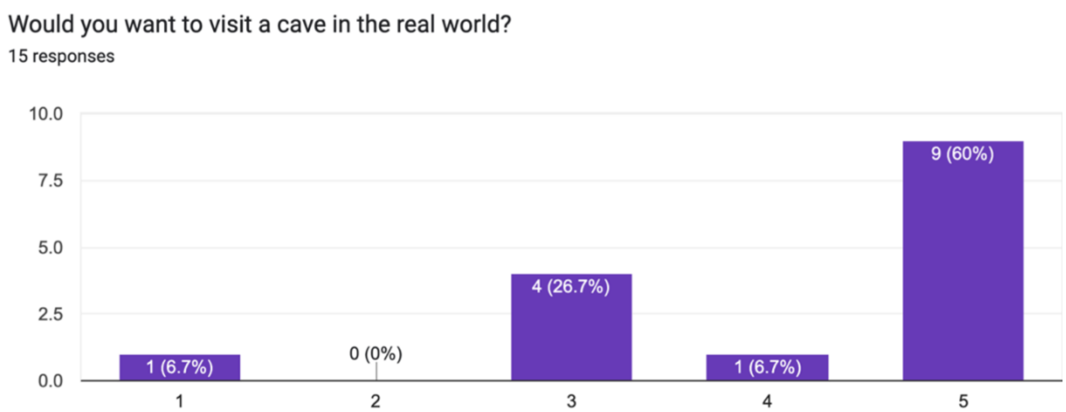


Fig. 60: Participants without sound.

T-test of Post-Experience Survey Results

Table. 1: When I was in the cave, I lost track of the world around me.

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	4	3.2
Variance	1.285714286	1.028571
Observations	15	15
Pooled Variance	1.157142857	

Hypothesized Mean Difference	0
df	28
t Stat	2.036700309
P(T<=t) one-tail	0.02561778
t Critical one-tail	1.701130934
P(T<=t) two-tail	0.05123556
t Critical two-tail	2.048407142

Table. 2: I blocked out things around when I was in the cave.

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	1.4	1.333333
Variance	1.114286	0.380952
Observations	15	15
Pooled Variance	0.747619	
Hypothesized Mean Difference	0	
df	28	
t Stat	0.211154	
P(T<=t) one-tail	0.417148	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.834296	
t Critical two-tail	2.048407	

Table. 3: I felt anxious while I was inside the cave.

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.2	2.8
Variance	1.171429	1.314286
Observations	15	15
Pooled Variance	1.242857	

Hypothesized Mean Difference	0
df	28
t Stat	0.982607
P(T<=t) one-tail	0.167108
t Critical one-tail	1.701131
P(T<=t) two-tail	0.334216
t Critical two-tail	2.048407

Table. 3: I felt disoriented while I was inside the cave.

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.6	4.133333
Variance	1.4	0.552381
Observations	15	15
Pooled Variance	0.97619	
Hypothesized Mean Difference	0	
df	28	
t Stat	-1.4783	
P(T<=t) one-tail	0.075245	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.15049	
t Critical two-tail	2.048407	

Table. 4: I lost myself in this experience.

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	4.266667	4.6
Variance	0.495238	0.4
Observations	15	15
Pooled Variance	0.447619	

Hypothesized Mean Difference	0
df	28
t Stat	-1.36444
P(T<=t) one-tail	0.091648
t Critical one-tail	1.701131
P(T<=t) two-tail	0.183295
t Critical two-tail	2.048407

Table. 5: I was absorbed in this experience.

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	4.333333	4.666667
Variance	0.52381	0.238095
Observations	15	15
Pooled Variance	0.380952	
Hypothesized Mean Difference	0	
df	28	
t Stat	-1.47902	
P(T<=t) one-tail	0.075149	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.150298	
t Critical two-tail	2.048407	

Table. 6: To what extent did the experience hold your attention?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.933333	3.933333
Variance	0.780952	1.352381
Observations	15	15
Pooled Variance	1.066667	

Hypothesized Mean Difference	0	
df	28	
t Stat	-2.65165	
P(T<=t) one-tail	0.006518	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.013037	
t Critical two-tail	2.048407	

Table. 7: How much effort did you put into exploring the cave?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.133333	3.2
Variance	1.12381	2.314286
Observations	15	15
Pooled Variance	1.719048	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.13925	
P(T<=t) one-tail	0.445125	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.890249	
t Critical two-tail	2.048407	

Table. 8: To what extend did you feel consciously aware of being in the real world while playing?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.733333	3.866667
Variance	1.495238	0.695238
Observations	15	15

Pooled Variance	1.095238	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.34891	
P(T<=t) one-tail	0.364883	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.729766	
t Critical two-tail	2.048407	

Table. 9: To what extent did you forget about your everyday concerns?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.866667	3
Variance	0.838095	1.428571
Observations	15	15
Pooled Variance	1.133333	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.343	
P(T<=t) one-tail	0.367081	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.734162	
t Critical two-tail	2.048407	

Table. 10: To what extent were you aware of yourself in your virtual cave surroundings?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3	3.8
Variance	1.285714	0.742857
Observations	15	15
Pooled Variance	1.014286	

Hypothesized Mean Difference	0
df	28
t Stat	-2.17541
P(T<=t) one-tail	0.019099
t Critical one-tail	1.701131
P(T<=t) two-tail	0.038199
t Critical two-tail	2.048407

Table. 11: To what extent did you feel like you were interacting with the cave environment?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.8	3.4
Variance	1.171429	1.542857
Observations	15	15
Pooled Variance	1.357143	
Hypothesized Mean Difference	0	
df	28	
t Stat	-1.41049	
P(T<=t) one-tail	0.084705	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.169409	
t Critical two-tail	2.048407	

Table. 12: To what extent was your sense of being in the cave environment stronger than your sense of being the real world?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.6	2.666667
Variance	1.257143	1.095238

Observations	15	15
Pooled Variance	1.17619	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.16835	
P(T<=t) one-tail	0.433761	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.867522	
t Critical two-tail	2.048407	

Table. 13: To what extent did you feel as though you were moving through the game according to your own will?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	1.333333	1.533333
Variance	0.666667	0.980952
Observations	15	15
Pooled Variance	0.82381	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.60346	
P(T<=t) one-tail	0.275531	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.551062	
t Critical two-tail	2.048407	

.

Table. 14: To what extent did you find navigating the cave challenging?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	2.6	2.666667
Variance	1.257143	1.095238

Observations	15	15
Pooled Variance	1.17619	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.16835	
P(T<=t) one-tail	0.433761	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.867522	
t Critical two-tail	2.048407	

Table. 15: Were there any times you wanted to give up?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	1.333333	1.533333
Variance	0.666667	0.980952
Observations	15	15
Pooled Variance	0.82381	
Hypothesized Mean Difference	0	
df	28	
t Stat	-0.60346	
P(T<=t) one-tail	0.275531	
t Critical one-tail	1.701131	
P(T<=t) two-tail	0.551062	
t Critical two-tail	2.048407	

.

Table. 16: To what extent did you enjoy the graphics and imagery?

t-Test: Two-Sample Assuming Equal Variances

	Variable 1	*Variable 2*
Mean	3.866667	4
Variance	0.695238	0.857143
Observations	15	15
Pooled Variance	0.77619	

Hypothesized Mean Difference	0
df	28
t Stat	-0.41446
P(T<=t) one-tail	0.340847
t Critical one-tail	1.701131
P(T<=t) two-tail	0.681694
t Critical two-tail	2.048407

Table. 17: The Python code used to conduct a t-test of the minimum and mean distance from landmarks.

```
Player_info = []
# Bat audio 3
ba3 = np.array([-1516.343674, 9136.946902])
for key in df:
  path = df[key][['X','Y']].to_numpy()
  sound = df[key].columns[0]
  distances = np.array([dist(p, ba3) for p in path])
  min_dist = distances.min()
  mean_dist = distances.mean()
  # print(f"min:{min_dist} mean: {mean_dist}")
  player_info.append({'Name': key,
                    'Sound': sound,
                    'BA3 min': min_dist,
                    'BA3 mean': mean_dist
                    })

df_players = pd.DataFrame(player_info)
df_players.groupby("Sound").mean()
# Extract the groups
no_sound = df_players[df_players['Sound'] == 'No Sound']
sound = df_players[df_players['Sound'] == 'Sound']

# Perform t-tests
t_test_min_dist = ttest_ind(no_sound['BA3 min'], sound['BA3 min'])
t_test_mean_dist = ttest_ind(no_sound['BA3 mean'], sound['BA3 mean'])

# Print the results
print("T-test for Min Distance Bat Audio:", t_test_min_dist)
print("T-test for Mean Distance Bat Audio:", t_test_mean_dist)
```

Works Cited

Anemone, Robert L., and Glenn C. Conroy, eds. *New Geospatial Approaches to the Anthropological Sciences*. Albuquerque: University of New Mexico Press, 2018.

Arrighi, Gillian, Zi Siang See, and Donovan Jones. "Victoria Theatre Virtual Reality: A Digital Heritage Case Study and User Experience Design." *Digital Applications in Archaeology and Cultural Heritage* 21 (June 2021): e00176. https://doi.org/10.1016/j.daach.2021.e00176.

Ashmore, Wendy. "Classic Maya Landscapes and Settlements." In *Mesoamerican Archaeology*, edited by Julia Hendon and Rosemary A. Joyce, 169–86. Blackwell Publishing, 2004.

Bassie-Sweet, Karen. *At the Edge of the World: Caves and Late Classic Maya World View*. Norman (Okla.): University of Oklahoma press, 1996.

Baumanova, Monika. "Sensory Synaesthesia: Combined Analyses Based on Space Syntax in African Urban Contexts." *African Archaeological Review* 37, no. 1 (March 1, 2020): 125–41. https://doi.org/10.1007/s10437-020-09368-9.

Bender, Barbara, ed. *Landscape: Politics and Perspectives*. Explorations in Anthropology. Providence: Berg, 1993.

Beyer, Christian. "Edmund Husserl." In *He Stanford Encyclopedia of Philosophy*, 2022. https://plato.stanford.edu/archives/win2022/entries/husserl/.

Brady, James E., and Wendy Ashmore. "Mountains, Caves, Water: Ideational Landscapes of the Ancient Maya." In *Archaeologies of Landscapes: Contemporary Perspectives*, edited by Wendy Ashmore and Bernard Knapp, 124–45. Blackwell Publishers, 1999.

Brentano, Franz. *Psychology from an Empirical Standpoint*. Routledge Classics. Abingdon, Oxon: Routledge, 2015.

Brezina, Pavol. "Acoustics of Historic Spaces as a Form of Intangible Cultural Heritage." *Antiquity* 87, no. 336 (June 1, 2013): 574–80. https://doi.org/10.1017/S0003598X00049139.

Bruchez, Margaret Sabom. "Artifacts That Speak for Themselves: Sounds Underfoot in Mesoamerica." *Journal of Anthropological Archaeology* 26, no. 1 (March 2007): 47–64. https://doi.org/10.1016/j.jaa.2006.02.001.

Brück, Joanna. "Experiencing the Past? The Development of a Phenomenological Archaeology in British Prehistory." *Archaeological Dialogues* 12, no. 1 (June 2005): 45–72. https://doi.org/10.1017/S1380203805001583.

Capper, J. E. "XXIII.— *Photographs of Stonehenge, as Seen from a War Balloon*." *Archaeologia* 60, no. 2 (1907): 571–571. https://doi.org/10.1017/S0261340900005208.

Chernhall, Robert. "The Impact of Computers on Archaeological Theory: An Appraisal and Projection." *Computers and the Humanities* 3, no. 1 (September 1968): 15–24.

Cignoni, P., M. Callieri, M. Corsini, M. Dellepiane, F. Ganovelli, and G. Ranzuglia. "MeshLab: An Open-Source Mesh Processing Tool." In *Eurographics Italian Chapter Proceedings*, edited by Vittorio Scarano, 129–36. Eurographics Italian Chapter Proceedings. Aire-la-Ville: Eurographics Assoc. [u.a.], 2008.

Crabtree, Stefani A., Devin A. White, Corey J. A. Bradshaw, Frédérik Saltré, Alan N. Williams, Robin J. Beaman, Michael I. Bird, and Sean Ulm. "Landscape Rules Predict Optimal Superhighways for the First Peopling of Sahul." *Nature Human Behaviour* 5, no. 10 (October 2021): 1303–13. https://doi.org/10.1038/s41562-021-01106-8.

Cummings, V. “Virtual Reality, Visual Envelopes, and Characterizing Landscape.” In *Handbook of Landscape Archaeology*, edited by W. A. Congress and B.D. Thomas, 285–91. Walnut Creek: Left Coast Press, 2010.

Cummings, Vicki, and A. W. R. Whittle. *Places of Special Virtue: Megaliths in the Neolithic Landscapes of Wales*. Cardiff Studies in Archaeology. Oxford : Oakville, CT: Oxbow ; David Brown Book Co. [distributor], 2004.

Dawson, Peter, Richard Levy, and Natasha Lyons. “‘Breaking the Fourth Wall’: 3D Virtual Worlds as Tools for Knowledge Repatriation in Archaeology.” *Journal of Social Archaeology* 11, no. 3 (October 2011): 387–402. https://doi.org/10.1177/1469605311417064.

DeFanti, Thomas A., Daniel Acevedo, Richard A. Ainsworth, Maxine D. Brown, Steven Cutchin, Gregory Dawe, Kai-Uwe Doerr, et al. “The Future of the CAVE.” *Central European Journal of Engineering* 1, no. 1 (March 1, 2011): 16–37. https://doi.org/10.2478/s13531-010-0002-5.

Di Franco, Paola Di Giuseppantonio, Carlo Camporesi, Fabrizio Galeazzi, and Marcelo Kallmann. “3D Printing and Immersive Visualization for Improved Perception of Ancient Artifacts.” *Presence: Teleoperators and Virtual Environments* 24, no. 3 (July 2015): 243–64. https://doi.org/10.1162/PRES_a_00229.

———. “3D Printing and Immersive Visualization for Improved Perception of Ancient Artifacts.” *Presence: Teleoperators and Virtual Environments* 24, no. 3 (July 2015): 243–64. https://doi.org/10.1162/PRES_a_00229.

———. “3D Printing and Immersive Visualization for Improved Perception of Ancient Artifacts.” *Presence: Teleoperators and Virtual Environments* 24, no. 3 (July 1, 2015): 243–64. https://doi.org/10.1162/PRES_a_00229.

Díaz-Andreu, Margarita, Gabriel García Atiénzar, Carlos García Benito, and Tommaso Mattioli. “Do You Hear What I See? Analyzing Visibility and Audibility in the Rock Art Landscape of the Alicante Mountains of Spain.” *Journal of Anthropological Research* 73, no. 2 (June 2017): 181–213. https://doi.org/10.1086/692103.

Đorđević, Zorana, and Dragan Novković. “Archaeoacoustic Research of Ljubostinja and Naupara Medieval Monastic Churches.” *Open Archaeology* 5, no. 1 (January 1, 2019): 274–83. https://doi.org/10.1515/opar-2019-0018.

Downey, Greg. “Listening to Capoeira: Phenomenology, Embodiment, and the Materiality of Music.” *Ethnomusicology* 46, no. 3 (2002): 487. https://doi.org/10.2307/852720.

Edmonds, Mark. “Who Said Romance Was Dead?” *Journal of Material Culture* 11, no. 1–2 (July 2006): 167–88. https://doi.org/10.1177/1359183506063019.

Eisenberg, Andrew. “Space.” In *Keywords in Sound*, edited by David Novak and Matt Sakakeeny. Durham ; London: Duke University Press, 2015.

Eve, Stuart. “Augmenting Phenomenology: Using Augmented Reality to Aid Archaeological Phenomenology in the Landscape.” *Journal of Archaeological Method and Theory* 19, no. 4 (December 2012): 582–600. https://doi.org/10.1007/s10816-012-9142-7.

———. “Losing Our Senses, an Exploration of 3D Object Scanning.” *Open Archaeology* 4, no. 1 (March 1, 2018): 114–22. https://doi.org/10.1515/opar-2018-0007.

Feld, Steven. “Acoustemology.” In *Keywords in Sound*, edited by David Novak. Durham ; London: Duke University Press, 2015.

———. “Places Sensed, Senses Placed: Toward a Sensuous Epistemology of Environments by Steven Feld.” In *Empire of the Senses: The Sensual Culture Reader*, edited by David Howes. Sensory Formations Series. Oxford ; New York: Berg, 2005.

Fleming, Andrew. “Megaliths and Post-Modernism: The Case of Wales.” *Antiquity* 79 (2005): 921–32.

———. “Phenomenology And the Megaliths of Wales: A Dreaming Too Far?” *Oxford Journal of Archaeology* 18, no. 2 (1999).

———. “Post-Processual Landscape Archaeology: A Critique.” *Cambridge Archaeological Journal* 16, no. 3 (2006): 267–80.

Galeazzi, Fabrizio, Holley Moyes, and Mark Aldenderfer. “Defining Best 3D Practices in Archaeology: Comparing Laser Scanning and Dense Stereo Matching Techniques for 3D Intrasite Data Recording.” *Advances in Archaeological Practice* 2, no. 4 (November 2014): 353–65. https://doi.org/10.7183/2326-3768.2.4.353.

Gann, Thomas. *The Maya Indians of Southern Yucatan and Northern British Honduras*, 1918.

Garner, Tom A. *Echoes of Other Worlds: Sound in Virtual Reality*. Cham: Springer International Publishing, 2018. https://doi.org/10.1007/978-3-319-65708-0.

Geoffroy-Schwinden, Rebecca. “Digital Approaches to Historical Acoustemologies: Replication and Reenactment.” In *Digital Sound Studies*, edited by Mary Caton Lingold, Darren Mueller, and Whitney Anne Trettien, 231–50. Durham: Duke University Press, 2018.

Gillings, Mark. “Chorography, Phenomenology and the Antiquarian Tradition.” *Cambridge Archaeological Journal* 21, no. 1 (February 2011): 53–64. https://doi.org/10.1017/S0959774311000035.

Goodwin, Graham, and Nicola Lercari. 2023. “Reconstructing Past Experience Using Virtual Reality.” In *Horizons of Phenomenology*, edited by Jeff Yoshimi, Philip Walsh, and Patrick Londen, 122:325–36. Contributions to Phenomenology. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-26074-2_17.

Goodwin, Graham, and Heather Richards-Rissetto. “Modelling Acoustics in Ancient Maya Cities: Moving Towards a Synesthetic Experience Using GIS & 3D Simulation,” November 12, 2020. https://doi.org/10.15496/PUBLIKATION-43230.

Grosman, Leore. “Reaching the Point of No Return: The Computational Revolution in Archaeology.” *Annual Review of Anthropology* 45, no. 1 (October 21, 2016): 129–45. https://doi.org/10.1146/annurev-anthro-102215-095946.

Hamilakis, Y. *Archaeology and the Senses: Human Experience, Memory, and Affect*. New York: Cambridge University Press, 2013.

Hamilton, Sue, Ruth Whitehouse, Keri Brown, Pamela Combes, Edward Herring, and Mike Seager Thomas. “Phenomenology in Practice: Towards a Methodology for a ‘Subjective’ Approach.” *European Journal of Archaeology* 9, no. 1 (2006): 31–71. https://doi.org/10.1177/1461957107077704.

Heidegger, Martin, John Macquarrie, and Edward S. Robinson. *Being and Time*. New York: HarperPerennial/Modern Thought, 2008.

Hendrix, Claudia, and Woodrow Barfield. “The Sense of Presence within Auditory Virtual Environments.” *Presence: Teleoperators and Virtual Environments* 5, no. 3 (January 1996): 290–301. https://doi.org/10.1162/pres.1996.5.3.290.

Hodder, I. “Postprocessual Archaeology.” In *Advances in Archaeological Method and Theory : Volume 8*, by Michael B. Schiffer, 1–26. Saint Louis, UNITED STATES:

Elsevier Science & Technology, 1985. http://ebookcentral.proquest.com/lib/ucm/detail.action?docID=1882715.
Houston, Stephen D., Stuart David, and Karl Taube. *The Memory of Bones: Body, Being, and Experience among the Classic Maya*. University of Texas Press, 2006.
Hurcombe, Linda. "A Sense of Materials and Sensory Perception in Concepts of Materiality." *World Archaeology* 39, no. 4 (December 1, 2007): 532–45. https://doi.org/10.1080/00438240701679346.
Husserl, Edmund. *Collected Works*. The Hague: M. Nijhoff Publishers, 1980.
———. *Logical Investigations*. Edited by Dermot Moran. International Library of Philosophy. London ; New York: Routledge, 2001.
———. *Phenomenology and the Foundations of the Sciences*. His Ideas Pertaining to a Pure Phenomenology and to a Phenomenological Philosophy, 3rd bk. The Hague ; Boston : Hingham, MA: M. Nijhoff Publishers ; distributors for the U.S. and Canada, Kluwer Boston, 1980.
Husserl, Edmund, Richard Rojcewicz, and Edmund Husserl. *Thing and Space: Lectures of 1907*. Edmund Husserl Collected Works, v. 7. Dordrecht ; Boston: Kluwer Academic Publishers, 1997.
Jennett, Charlene, Anna L. Cox, Paul Cairns, Samira Dhoparee, Andrew Epps, Tim Tijs, and Alison Walton. "Measuring and Defining the Experience of Immersion in Games." *International Journal of Human-Computer Studies* 66, no. 9 (September 2008): 641–61. https://doi.org/10.1016/j.ijhcs.2008.04.004.
Johnson, Matthew. *Archaeological Theory: An Introduction*. 2nd ed. Chichester, West Sussex, UK ; Malden, MA: Wiley-Blackwell, 2010.
Johnson, Matthew H. "Phenomenological Approaches in Landscape Archaeology." *Annual Review of Anthropology* 41, no. 1 (October 21, 2012): 269–84. https://doi.org/10.1146/annurev-anthro-092611-145840.
Katz, Jared. "A Blustery Melody: An Analysis of the Classic Maya's Use of Music as a Mediatory Art Form." In *Maya Cosmology - Terrestrial and Celestial Landscapes: Proceedings of the 19th European Maya Conference, Bratislava, November 17-22, 2014*, edited by Milan Kováč, Harri Kettunen, and Guido Krempel, 118–29. Acta Mesoamericana 29. Munich: Verlag Anton Saurwein, 2019.
Kazhdan, Michael, Matthew Bolitho, and Hugues Hoppe. "Poisson Surface Reconstruction." In *Eurographics Symposium on Geometry Processing*, 2006.
Kern, Angelika C., and Wolfgang Ellermeier. "Audio in VR: Effects of a Soundscape and Movement-Triggered Step Sounds on Presence." *Frontiers in Robotics and AI* 7 (February 21, 2020): 20. https://doi.org/10.3389/frobt.2020.00020.
———. "Audio in VR: Effects of a Soundscape and Movement-Triggered Step Sounds on Presence." *Frontiers in Robotics and AI* 7 (February 21, 2020): 20. https://doi.org/10.3389/frobt.2020.00020.
Knabb, Kyle A., Jurgen P. Schulze, Falko Kuester, Thomas A. DeFanti, and Thomas E. Levy. "Scientific Visualization, 3D Immersive Virtual Reality Environments, and Archaeology in Jordan and the Near East." *Near Eastern Archaeology* 77, no. 3 (September 2014): 228–32. https://doi.org/10.5615/neareastarch.77.3.0228.
Kopij, Kamil, and Adam Pilch. "The Acoustics of *Contiones* , or How Many Romans Could Have Heard Speakers." *Open Archaeology* 5, no. 1 (January 1, 2019): 340–49. https://doi.org/10.1515/opar-2019-0021.

Kosakowsky, Laura, Holley Moyes, Mark Robinson, and Barbara Voorhies. “Ceramics of Las Cuevas and the Chiquibul: At World’s End.” *Research Reports in Belizean Archaeology* 10 (2013): 25–32.

Lash, Ryan. “Movement, Materials, and Intersubjectivity: Insights from Western Ireland.” In *ROUTLEDGE HANDBOOK OF SENSORY ARCHAEOLOGY*. S.l.: ROUTLEDGE, 2022.

———. “Movement, Materials, and Intersubjectivity: Insights from Western Ireland By.” In *The Routledge Handbook of Sensory Archaeology*, edited by Robin Skeates and Jo Day, 130–44. Routledge Handbooks. London New York: Routledge, Taylor & Francis Group, 2020.

Lefroy, H. “On Some Pottery, Flint Weapons, and Other Objects from British Honduras.” *The Archaeological Journal* 41 (1884): 47–53.

Lercari, Nicola, Arianna Campiani, and Rodrigo Liendo Stuardo. “Intra-Site Digital Documentation of the Ancient Maya City of Palenque, Mexico.” In *Proceedings of DH 2018*. San Francisco, CA: IEEE, 2018.

Lozano Bravo, H., E. Lo, H. Moyes, D. Rissolo, S. Montgomery, and F. Kuester. “A METHODOLOGY FOR CAVE FLOOR BASEMAP SYNTHESIS FROM POINT CLOUD DATA: A CASE STUDY OF SLAM-BASED LIDAR AT LAS CUEVAS, BELIZE.” *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences* X-M-1–2023 (June 23, 2023): 179–86. https://doi.org/10.5194/isprs-annals-X-M-1-2023-179-2023.

Machause López, Sonia, and Robin Skeates. “Caves, Senses, and Ritual Flows in the Iberian Iron Age: The Territory of Edeta.” *Open Archaeology* 8, no. 1 (February 15, 2022): 1–29. https://doi.org/10.1515/opar-2022-0222.

Mathews, Jennifer P., and James F. Garber. “MODELS OF COSMIC ORDER: Physical Expression of Sacred Space among the Ancient Maya.” *Ancient Mesoamerica* 15, no. 1 (January 2004): 49–59. https://doi.org/10.1017/S0956536104151031.

McCoy, Mark D. “Defining the Geospatial Revolution in Archaeology.” *Journal of Archaeological Science: Reports* 37 (June 2021): 102988. https://doi.org/10.1016/j.jasrep.2021.102988.

Mcnatt, Logan. “Cave Archaeology of Belize.” *Journal of Cave and Karst Studies* 58, no. 2 (1996): 81–100.

Merleau-Ponty, Maurice. *The Phenomenology of Perception*. London: Routledge, 2005.

Millhauser, John K., and Christopher T. Morehart. “The Ambivalence of Maps: A Historical Perspective on Sensing and Representing Space in Mesoamerica.” In *Digital Methods and Remote Sensing in Archaeology*, edited by Maurizio Forte and Stefano Campana, 247–68. Cham: Springer International Publishing, 2016. https://doi.org/10.1007/978-3-319-40658-9_11.

Mlekuz, D. “Listening to Landscapes: Modelling Past Soundscapes in GIS.” *Internet Archaeology* 16 (2004).

Monteleone, Kelly, Amy E. Thompson, and Keith M. Prufer. “Virtual Cultural Landscapes: Geospatial Visualizations of Past Environments.” *Archaeological Prospection* 28, no. 3 (July 2021): 379–401. https://doi.org/10.1002/arp.1830.

Morton, Shawn. *Interdisciplinary Approaches to the Ancient Maya Underworld: Exploring the Rise and Fall of Maya Centres in Central Belize from the Cave Context*. Archaeology of the Maya, volume 2. Oxford: BAR Publishing, 2018.

Moser, Stephanie. "Archaeological Visualization:Early Artifact Illustration and the Birth of the Archaeological Image." In *Archaeological Theory Today*, edited by Ian Hodder, 2nd ed., 292–323. Cambridge, UK ; Malden, MA: Polity Press, 2012.

Moyes, Holley. "Capturing the Forest: Ancient Maya Ritual Caves as Built Environments." In *Approaches to Monumental Landscapes of the Ancient Maya*, by Holley Moyes, 313–34. University Press of Florida, 2020. https://doi.org/10.5744/florida/9780813066226.003.0015.

———. "Constructing the Underworld: The Built Environment in Ancient Mesoamerican Caves." In *Heart of Earth: Studies in Maya Ritual Cave Use*, edited by James Brady, 95–111, 2012.

———. "Ritual Cave Use Among the Ancient Maya." In *The Maya World*, 227–306, 2020.

———. "Xibalba, the Place of Fear: Caves and the Ancient Maya Underworld." *ARYS: Antigüedad, Religiones y Sociedades*, no. 14 (May 16, 2018): 171. https://doi.org/10.20318/arys.2017.3990.

———.The Life and Afterlife of Phenomenology in Archaeological Theory and Practice." In *Horizons of Phenomenology*, edited by Jeff Yoshimi, Philip Walsh, and Patrick Londen, 122:307–24. Contributions to Phenomenology. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-26074-2_16.

Moyes, Holley, and James Brady. "Caves as Sacred Space in Mesoamerica." In *Sacred Darkness : A Global Perspective on the Ritual Use of Caves*, edited by Holley Moyes, 151–70, 2012.

Moyes, Holley, and Shane Montgomery. "Mapping Ritual Landscapes Using Lidar: Cave Detection through Local Relief Modeling." *Advances in Archaeological Practice* 4, no. 3 (August 2016): 249–67. https://doi.org/10.7183/2326-3768.4.3.249.

Moyes, Holley, Lillian Rigoli, Stephanie Huette, Daniel R. Montello, Teenie Matlock, and Michael J. Spivey. 2021. "Darkness and the Imagination: The Role of Environment in the Development of Spiritual Beliefs." In *The Oxford Handbook of Light in Archaeology*, by Holley Moyes, Lillian Rigoli, Stephanie Huette, Daniel R. Montello, Teenie Matlock, and Michael J. Spivey, edited by Costas Papadopoulos and Holley Moyes, 84–104. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198788218.013.4.

Murphy, Damian, Simon Shelley, Aglaia Foteinou, Jude Brereton, and Helena Daffern. "Acoustic Heritage and Audio Creativity: The Creative Application of Sound in the Representation, Understanding and Experience of Past Environments." *Internet Archaeology*, no. 44 (2017). https://doi.org/10.11141/ia.44.12.

Murrieta-Flores, Patricia, and Bruno Martins. "The Geospatial Humanities: Past, Present and Future." *International Journal of Geographical Information Science* 33, no. 12 (December 2, 2019): 2424–29. https://doi.org/10.1080/13658816.2019.1645336.

Opitz, Rachel. "An Experiment in Using Visual Attention Metrics to Think About Experience and Design Choices in Past Places." *Journal of Archaeological Method and Theory* 24, no. 4 (December 2017): 1203–26. https://doi.org/10.1007/s10816-016-9310-2.

Opitz, Rachel, and W. Fred Limp. "Recent Developments in High-Density Survey and Measurement (HDSM) for Archaeology: Implications for Practice and Theory." *Annual Review of Anthropology* 44, no. 1 (October 21, 2015): 347–64. https://doi.org/10.1146/annurev-anthro-102214-013845.

Ortoleva, Jacqueline K. “Sounds of Etruria: Aural Characteristics of the Tomba Dell’Orco, Tarquinia.” *Antiquity* 95, no. 383 (October 2021): 1179–94. https://doi.org/10.15184/aqy.2021.111.

Palka, Joel W. *Maya Pilgrimage to Ritual Landscape: Insights from Archaeology, History, and Ethnography*. Archaeologies of Landscapes in the Americas Series. Albuquerque: University of New Mexico Press, 2014.

Papadopoulos, Costas, Yannis Hamilakis, Nina Kyparissi-Apostolika, and Marta Díaz-Guardamino. “Digital Sensoriality: The Neolithic Figurines from Koutroulou Magoula, Greece.” *Cambridge Archaeological Journal* 29, no. 4 (November 2019): 625–52. https://doi.org/10.1017/S0959774319000271.

Parsons, Jeffrey T. “Archaeological Settlement Patterns.” *Annual Review of Anthropology* 1 (1972): 127–50.

Peterson, Rick. “William Stukeley: An Eighteenth-Century Phenomenologist?” *Antiquity* 77, no. 296 (June 2003): 394–400. https://doi.org/10.1017/S0003598X00092371.

Pettey, Gary, Cheryl Campanella Bracken, Bridget Rubenking, Michael Buncher, and Erika Gress. “Telepresence, Soundscapes and Technological Expectation: Putting the Observer into the Equation.” *Virtual Reality* 14, no. 1 (March 2010): 15–25. https://doi.org/10.1007/s10055-009-0148-8.

Petersen, Gustav Bøg, Giorgos Petkakis, and Guido Makransky. 2022. “A Study of How Immersion and Interactivity Drive VR Learning.” *Computers & Education* 179 (April):104429. https://doi.org/10.1016/j.compedu.2021.104429.

Phillips, C. W. “Archaeology and the Ordnance Survey.” *Antiquity* 33, no. 131 (September 1959): 195–204. https://doi.org/10.1017/S0003598X00027496.

Primeau, Kristy E., and David E. Witt. “Soundscapes in the Past: Investigating Sound at the Landscape Level.” *Journal of Archaeological Science: Reports* 19 (June 2018): 875–85. https://doi.org/10.1016/j.jasrep.2017.05.044.

Pujol, Laia, and Erik Champion. “Evaluating Presence in Cultural Heritage Projects.” *International Journal of Heritage Studies* 18, no. 1 (January 2012): 83–102. https://doi.org/10.1080/13527258.2011.577796.

Pujol-Tost, Laia. “‘3D·CoD’: A New Methodology for the Design of Virtual Reality-Mediated Experiences in Digital Archeology.” *Frontiers in Digital Humanities* 4 (August 11, 2017): 16. https://doi.org/10.3389/fdigh.2017.00016.

———. “Cultural Presence in Virtual Archaeology: An Exploratory Analysis of Factors.” *Presence: Teleoperators and Virtual Environments* 26, no. 03 (May 2018): 247–63. https://doi.org/10.1162/pres_a_00296.

———. “Did We Just Travel to the Past? Building and Evaluating With Cultural Presence Different Modes of VR-Mediated Experiences in Virtual Archaeology.” *Journal on Computing and Cultural Heritage* 12, no. 1 (February 28, 2019): 1–20. https://doi.org/10.1145/3230678.

Rua, Helena, and Pedro Alvito. “Living the Past: 3D Models, Virtual Reality and Game Engines as Tools for Supporting Archaeology and the Reconstruction of Cultural Heritage – the Case-Study of the Roman Villa of Casal de Freiria.” *Journal of Archaeological Science* 38, no. 12 (December 2011): 3296–3308. https://doi.org/10.1016/j.jas.2011.07.015.

Sciuto, Claudia, Anna Foka, Mattis Lindmark, and Jim Robertsson. “Exploring Fragmented Data: Environments, People and the Senses in Virtual Reality.” In *Capturing the Senses*,

edited by Giacomo Landeschi and Eleanor Betts, 85–103. Quantitative Methods in the Humanities and Social Sciences. Cham: Springer International Publishing, 2023. https://doi.org/10.1007/978-3-031-23133-9_5.
Shams, Ladan, Yukiyasu Kamitani, and Shinsuke Shimojo. "What You See Is What You Hear." *Nature* 408, no. 6814 (December 2000): 788–788. https://doi.org/10.1038/35048669.
Sharer, Robert J., and Loa P. Traxler. *The Ancient Maya*. 6th ed. Stanford, Calif: Stanford University Press, 2006.
Skeates, Robin. "Soundscapes of Temple Period Malta." *Time and Mind* 10, no. 1 (January 2, 2017): 61–67. https://doi.org/10.1080/1751696X.2016.1267920.
Stone, Andrea Joyce. *Images from the Underworld: Naj Tunich and the Tradition of Maya Cave Painting*. 1st ed. Austin: University of Texas Press, 1995.
Stukeley, William. *Abury, A Temple of the British Druids, With Some Others, Described*, 1740. https://www.gutenberg.org/files/64626/64626-h/64626-h.htm.
Susmann, Natalie M. "Regional Ways of Seeing: A Big-Data Approach for Measuring Ancient Visualscapes." *Advances in Archaeological Practice* 8, no. 2 (May 2020): 174–91. https://doi.org/10.1017/aap.2020.6.
Thomas, Julian. "Archaeologies of Place and Landscape." In *Archaeological Theory Today*, edited by Ian Hodder. Blackwell Publishers, 2001.
———. "Archaeologies of Place and Landscape." In *Archaeological Theory Today*, edited by Ian Hodder. Blackwell Publishers, 2001.
———. "Archaeologies of Place and Landscape." In *Archaeological Theory Today*, edited by Ian Hodder, 2nd ed. Cambridge, UK ; Malden, MA: Polity Press, 2012.
———. "On the Ocularcentrism of Archaeology." In *Archaeology and the Politics of Vision in a Post-Modern Context*, edited by Julian Thomas and Vítor Oliveira Jorge. Newcastle upon Tyne, UK: Cambridge Scholars Pub, 2008. https://www.academia.edu/216224/On_the_ocularcentrism_of_archaeology._2009_In_Julian_Thomas_Vitor_Jorge_eds._Archaeology_and_the_Politics_of_Vision_in_a_Post-Modern_Context_1-12._Cambridge_Scholars_Press.
———. "Phenomenology And Material Culture." In *Handbook of Material Culture*, 43–57. Sage Publications, 2006.
Thomas, Wing-CDR. H. Hamshaw. "Recent Developments in Air Photography." *Nature* 156, no. 3962 (October 1, 1945): 409–11. https://doi.org/10.1038/156409a0.
Till, Rupert. "Sound Archaeology: Terminology, Palaeolithic Cave Art and the Soundscape." *World Archaeology* 46, no. 3 (May 27, 2014): 292–304. https://doi.org/10.1080/00438243.2014.909106.
Tilley, C. *A Phenomenology of Landscape*. Oxford: Berg Publishers, 1994.
Tost, Laia Pujol, and Maria Economou. "Worth a Thousand Words? The Usefulness of Immersive Virtual Reality for Learning in Cultural Heritage Settings." *International Journal of Architectural Computing* 7, no. 1 (2009): 157–76.
———. "Worth a Thousand Words? The Usefulness of Immersive Virtual Reality for Learning in Cultural Heritage Settings." *International Journal of Architectural Computing* 7, no. 1 (January 2009): 157–76. https://doi.org/10.1260/147807709788549367.

Tringham, Ruth, and Annie Danis. “Doing Sensory Archaeology: The Challenges.” In *The Routledge Handbook of Sensory Archaeology*, edited by Robin Skeates and Jo Day. Routledge Handbooks. London New York: Routledge, Taylor & Francis Group, 2020.

University of York, Damian Murphy, Simon Shelley, University of York, Aglaia Foteinou, University of Wolverhampton, Jude Brereton, University of York, Helena Daffern, and University of York. “Acoustic Heritage and Audio Creativity: The Creative Application of Sound in the Representation, Understanding and Experience of Past Environments.” *Internet Archaeology*, no. 44 (2017). https://doi.org/10.11141/ia.44.12.

Valenzuela, Jose, Margarita Díaz-Andreu, and Carles Escera. “Psychology Meets Archaeology: Psychoarchaeoacoustics for Understanding Ancient Minds and Their Relationship to the Sacred.” *Frontiers in Psychology* 11 (December 18, 2020): 550794. https://doi.org/10.3389/fpsyg.2020.550794.

VanValkenburgh, Parker, and J. Andrew Dufton. “Big Archaeology: Horizons and Blindspots.” *Journal of Field Archaeology* 45, no. sup1 (February 20, 2020): S1–7. https://doi.org/10.1080/00934690.2020.1714307.

Vogt, Evon, and David Stuart. “Some Notes on Ritual Caves among the Ancient and Modern Maya.” In *In the Maw of the Earth Monster: Studies of Mesoamerican Ritual Cave Use*, edited by James Brady and Keith Prufer, 155–80, 2005.

Whallon, Robert. “The Computer in Archaeology: A Critical Survey.” *Computers and the Humanities* 7, no. 1 (1972): 30–41.

Wiebe, Eric N., Allison Lamb, Megan Hardy, and David Sharek. “Measuring Engagement in Video Game-Based Environments: Investigation of the User Engagement Scale.” *Computers in Human Behavior* 32 (March 2014): 123–32. https://doi.org/10.1016/j.chb.2013.12.001.

Witmer, Bob G., and Michael J. Singer. 1998. “Measuring Presence in Virtual Environments: A Presence Questionnaire.” *Presence: Teleoperators and Virtual Environments* 7 (3): 225–40. https://doi.org/10.1162/105474698565686.

Witmore, Christopher L. “Vision, Media, Noise and the Percolation of Time: Symmetrical Approaches to the Mediation of the Material World.” *Journal of Material Culture* 11, no. 3 (November 2006): 267–92. https://doi.org/10.1177/1359183506068806.

Wrobel, Gabriel D., Jack A. Biggs, and Amy L. Hair. “Digital Modeling for Bioarchaeologists.” *Advances in Archaeological Practice* 7, no. 1 (February 2019): 47–54. https://doi.org/10.1017/aap.2018.47.

Yoshimi, Jeffrey. “Prospects for a Naturalized Phenomenology.” In *Philosophy of Mind and Phenomenology: Conceptual and Empirical Approaches*, edited by Daniel O. Dahlstrom, 1 [edition]. Routledge Research in Phenomenology 2. New York: Routledge, 2016.