UTILIZING AUGMENTED REALITY FOR EDUCATIONAL UNDERSTANDING AND CONSTRUCTION OF TRADITIONAL HALE

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Abstract

The revitalization of traditional Hawaiian Hales is an opportunity for community gathering, the restoration of historic structures and practices, and an opportunity for cultural teachings.[1] [2] Tacit knowledge embedded in Hale design including thatching, stacking and securing each stone, log, frond, and grass bundle serves to revive and restore these building practices and instills pride that comes from traditional Hawaiian values that are alive and well.[3] [4] However, such tacit knowledge has been an elusive subject due to the difficulty in articulation, record keeping, and communication.[5] [6] Furthermore, the oral tradition for transferring the tacit knowledge in Hawaiʻi makes it more challenging to convert it to explicit knowledge for the future generation of Hawaiʻi.[7]

By connecting virtual and real worlds, Augmented Reality (AR) serves to create a reality that is supplemental to the physical environment.[8] AR provides new possibilities for innovative

[1] Abernethy, Jane Fulton, Suelyn Ching Tune, and Julie Stewart Williams. Made in Hawaiʻi. Hono-lulu: University of Hawaii Press, 1983
[2] Bryan, E. H. "6. The Home." Essay. In Ancient Hawaiian Life, 18–21. Honolulu, HI,, HI: Books about Hawaii, 1950
[3] Apple, Russell Anderson. Hawaiian Thatched House: Use, Construction, Adaptation. San Fran-cisco, CA: U.S. National Park Service, 1971
[4] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003
[5] Ambrosini, Veronique, and Cliff Bowman. "Tacit Knowledge: Some Suggestions for Operationalization." Journal of Management Studies 38, no. 6 (2001): 811–29. https://doi.org/10.1111/1467-6486.00260.
[6] Dampney, Kit, Peter Busch, and Debbie Richards. "The Meaning of Tacit Knowledge." Australasian Journal of Information Systems 10, no. 1 (2002): 438. https://doi.org/10.3127/ajis.v10i1.438
[7] Nonaka, Ikujiro, and Hirotaka Takeuchi. "The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation." Oxford University Press 29, no. 4 (1995): 592. https://doi.org/10.1016/0024-6301(96)81509-3
[8] Caudell, T.P., and D.W. Mizell. "Augmented Reality: An Application of Heads-up Display Technology to Manual Manufacturing Processes." Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences, 1992, 659–669. https://doi.org/10.1109/hicss.1992.183317

education, and they have been increasingly recognized by educational researchers.[9] By adding an enhanced layer of computer-generated information to the real-world environment, AR allows a user to interact with two- and three-dimensional synthetic objects in real-time, visualize context-specific complex spatial relationships and abstract concepts, and experience phenomena with a full-scale immersion.[10] Furthermore, AR provides interpersonal communication among the participants of a shared AR experience.[11] In the area of Cultural Heritage (CH) education, the implementation of AR is already acknowledged to improve a student's learning experience and motivation. As the criteria for the successful AR educational system, 1) the ease of usability, 2) enriched content creation, 3) information management, and 4) right technology are highlighted.[12]

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[9] Ersozlu, Alpay, Mehmet Karakus, and Aaron C. Clark. "Augmented Reality Research in Education: A Bibliometric Study." EURASIA Journal of Mathematics, Science and Technology Education 15, no. 10 (2019). https://doi.org/10.29333/ejmste/103904

[10] Klopfer, Eric, and Kurt Squire. "Environmental Detectives—the Development of an Augmented Reality Platform for Environmental Simulations." Educational Technology Research and Development 56, no. 2 (2007): 203–28. https://doi.org/10.1007/s11423-007-9037-6

[11] Carmigniani, Julie, and Borko Furht. "Augmented Reality: An Overview." Handbook of Augmented Reality, 2011, 3–46. https://doi.org/10.1007/978-1-4614-0064-6_1

[12] González Vargas, Juan Camilo, Ramon Fabregat, Angela Carrillo-Ramos, and Teodor Jové. "Survey: Using Augmented Reality to Improve Learning Motivation in Cultural Heritage Studies." Applied Sciences 10, no. 3 (2020): 897. https://doi.org/10.3390/app10030897.

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Chapter 1: Introduction

1.1 Project Statement

We live in an age where modern technology has become an integral part of our day-to-day lives. People can be separated by vast distances while staying connected through the use of technology. The Internet, Phones, Zoom, Skype, Texting, Social Media, and many more aspects of technology have made the world smaller, closing cultural and physical divides amongst people of all ages and nationalities. By making use of technology involving immersive digital realities, the following research asks these questions: 1) Is it possible to use digital reality within a physical space to allow the user to learn through virtual assembly? 2) How can we link historical construction and methodologies from traditional Hawaiian Hales for contemporary studies in digital realities?

Digital Realities take users and immerse them in a world that can either separate or link the digital space with physical reality. A way to link design and building information through digital spaces is by utilizing the tacit knowledge that comes naturally through experience and practice involved in such a topic. Tacit knowledge is defined as "knowledge that is hard to quantify or pass from one person to another through verbal or written communication."[13] Tacit knowledge includes skills like speaking a language, playing a musical instrument, or carving a figurine out of a piece of wood, along with basic life skills such as facial recognition.[14]

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[13] Surbhi. "Difference between Explicit Knowledge and Tacit Knowledge (with Comparison Chart)." Key Differences, July 30, 2020. https://keydifferences.com/difference-between-explicit-knowledge-and-tacit-knowledge.html.
[14] Ibid

The following research will focus on the tacit knowledge of traditional Hawaiian Hales. To provide some background information between 124 and 11200 AD, the Hawaiian Islands were first settled by Polynesians, and the Hawaiian civilization was born. For the next 500 years, this civilization was isolated from outside contact, and from this isolation, Hawaiian culture was created. Due to the warm climate of the Hawaiian islands, the shelters created by the Hawaiian people were well adapted to the tropics and provided storage and/or protection against rough weather. Hawaiian Hales are either single houses or complex houses for chiefs and nobles of the island. The Hale is made out of grass, a wooden framework consisting of a ridgepole, rafters, and purlins. The most common grass used for the Hale is sweet pili grass, and other thatching included pandanus leaves, ti, sugar cane leaves, or banana trunk fiber. Braided ʻuki ʻuki grass, coconut husk fiber, or ʻie ʻie are used for lashing with no addition of nails. Hawaiian Hales typically had a small door and no windows.

During the early 1800s, traditional grass Hales still prevailed, though some materials were different due to colonization by the West. However, by the 21st century, it is almost impossible to find traditional structures outside of historical and cultural preservation sites. with colonization by the West, the Hawaiian Hale has diminished from the landscape in Hawaiʻi.[15]

The building practices of Hawaiian Hale's also incorporate tacit knowledge such as building materials, techniques, and environmental design. Tacit knowledge allows for the preservation of such building practices that was acquired by Native Hawaiians which is still in use today through preservation and continued education of future generations.[16]

[15] "Ancient Hawai`i." Architecture - hawaii history - architecture, n.d. http://www.hawaiihistory.org/index.cfm?fuseaction=ig.page&CategoryID=280.
[16] Ibid

In this research, augmented reality is used as an educational application for Hale construction and is proposed for reviving Hales as a place for community gathering, education, and cultural practitioners. Today the Hale can be categorized by the ROH (the Revision Ordinance of Honolulu) into four different types of classic Hale styles. These unique styles include A-Frame (Hale Waʻa), open wall (Halawai), lean-to (Kuʻai), or fully enclosed (Noa). In addition, each variety of Hale are used for specific functions including eating, sleeping, assembling, retailing, and storage. These Hales have been studied for 1) creating the historical and cultural contents, 2) developing geometric models, and 3) translating the construction and assembly process of the Hale into a sequence of design actions with the models.

Additionally, Rhinoceros 3D and visual programming language Grasshopper 3D are employed with the plug-in application Fologram. This proposed application consists of 1) analysis of Hale, 2) initiation of AR, 3) synthesis process of Hale, and 4) simulation of Hale through the interactive construction process. The proposed application will provide a dynamic learning experience for the Hale by combining both the real and digital environments, enabling the visualization of the design in its intended construction and assembly process with real-time feedback. The implementation of the proposed application is explained, and the usage of the application is also demonstrated in this research.

1.2 Outline of Research

The following chapters of this document will introduce and follow the idea of using tacit knowledge with immersive reality gear, a HoloLens, to teach construction and assembly of a traditional Hale to users. By providing examples of the technology in use, the following chapters share how to engage users to “learn through building” by ways of holographic assembly.

Chapter 2 is an analysis of what the traditional Hale is and how it has changed over time. The Hale, like any architectural structure, has evolved during the hundreds of years Hawaiians lived in Hawaiʻi. When Hawaiians first landed in Hawaiʻi they lived inland, mostly in natural cave formations, but over time they moved outland to the coast and created port cities, resulting in the many types of Hales we now know of today. Furthermore, colonization of the West influenced Hales which starting in 1837 started to have windows, high ceilings, and large portal entrances.[17] This chapter aims to explain to the reader the history of Hawaiian Hales and the evolution of their construction methods.

Chapter 3 gives the reader a deeper understanding of the technologies that bring different forms of realities--augmented, mixed reality, and virtual reality--are used together in a spectrum. The literature shows how the different types of technological realities are applied to everyday use and how accessible they can be. Additionally, this chapter goes further in-depth about the devices that are used in the experimentation process and what the advantages are to each device.

Chapter 4 shares different examples of how the technology is used and applied in real-world settings. Each example shares a key element to understanding where the technology currently stands and how the technology can be pushed further for design integration and learning. Through reviewing the literature and projects that have come before, this chapter helps to set up the basis of methodologies for experimentation.

Chapter 5 applies the ideas from chapter 4 and implements them in experiments that develop the methodology used for the final application. Chapter 5 is where the user of this

[17] "Ancient Hawai`i." Architecture - hawaii history - architecture, n.d. http://www.hawaiihistory.org/index.cfm?fuseaction=ig.page&CategoryID=280

research project will engage with the physical space alongside the fabricated digital space simultaneously to learn through the building process. This chapter starts off with understanding how to use the platform in which each experiment takes place and how the different experiments grow through progression.

Chapter 6 considers the variety of different traditional Hales and shares information about each holographic assembly. This chapter takes the practices from methodologies, in chapter 5, and uses them in the real-world application of constructing a physical model of a traditional Hale with the use of Augmented Reality via a HoloLens. The use of the HoloLens in the assembly of a Hale shares vital information that gives the user hands-on, tacit, information about this historic and cultural practice of construction. By having the user touch real-life building materials and create a Hale in the physical world with the help of Augmented Reality a deeper sense of cultural understanding can occur. This real-world application of Augmented Reality elicits tacit learning to occur where previously it could not, due to a lack of construction know-how or cultural barriers. The union of hands-on learning with an Augmented Reality device such as HoloLens will make this type of historic building more accessible to a layperson.

Chapter 7 concludes the research and the experimentation done with utilizing the AR system and addresses the possibilities for future uses. Discussion is then further addressed on the achievements and implications of the application in the experiments.

Chapter 2: Understanding the Hale

2.1 History

When Polynesians arrived in the Hawaiian Islands, the ancestors of modern-day Hawaiians, they had full knowledge of how to build houses with thatched roofs and upright walls.[18] These Hawaiian houses are called Hales. Due to the migratory nature of Polynesians, many island societies share similar terms and styles for their housing constructions. Though details might have changed, and architectural styles evolved there are still ancient Polynesian traditions that can be seen in Hawaiian Hales throughout the decades.[19]

Shelter was an important necessity for ancient Hawaiians and due to the climate of the Hawaiian Islands there was neither excessive heat nor cold, perhaps the only element that Native Hawaiians needed protection against was heavy rainfall.[20] Hawaiians did not have fortified towns or castles, though there was plenty of warfare between rival communities.[21] There were no mountain retreats found in other Polynesian islands such as Fiji or Rapa, though small groups of Hawaiians would take refuge in caves or other secret places.[22] In old Hawaiʻi there were no cities or large villages, the size of communities was limited by the extent of nearby areas of cultivation or fishing places.[23] Most of the villages were located near the ocean where canoe landing could be made with ease.

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[18] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003.
[19] Ibid
[20] Bryan, E. H. "6. The Home." Essay. In Ancient Hawaiian Life, 18–21. Honolulu, HI,, HI: Books about Hawaii, 1950
[21] Ibid
[22] Ibid
[23] Ibid

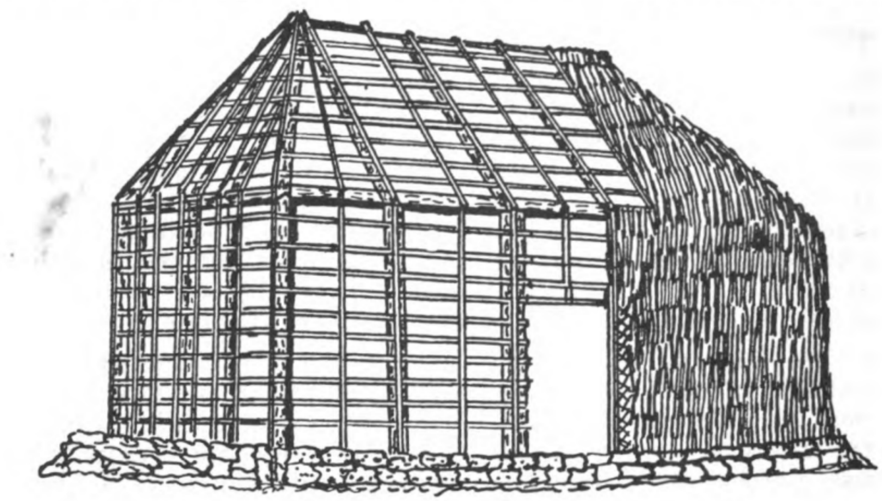

Figure 1. Hipped Hale Noa

Source: Buck, 2003

The Hawaiian Islands had fertile valleys and mountain slopes that grew coconut palms, hau, kou, and breadfruit trees along with gardens that were tended by Native Hawaiians.[24] The land provided enough building materials to allow for ample supplies in the construction of Hales. There are few early descriptions of Hawaiian villages, made before the structures, Hales, were altered from colonization by the West.[25] Captain Cook described the village of Waimea, Kauai as houses that were scattered about without any apparent order or method of orientation.[26] These are the earliest recorded records of Hawaiian villages due to the oral tradition of ancient Hawaiians, and such records are only partially accurate due to the discriminatory viewpoint of Captain Cook who thought Natives were savages. Hales were made with pili grass that grew abundantly in the lowlands and other materials were used in certain localities.[27] For example in the Puna district on the island of Hawaiʻi, most of the houses were thatched with lauhala due to

[24] Bryan, E. H. “6. The Home.” Essay. In Ancient Hawaiian Life, 18–21. Honolulu, HI,, HI: Books about Hawaii, 1950
[25] Ibid
[26] Ibid
[27] Ibid

the abundance of pandanus trees, additionally, sometimes sugar cane and ti leaves were used as well.[28]

Only the best woods such as naio, uhiuhi, kauila, mamane, kamani, koa, and other forest trees were used for the framework of the Hales. The framework was skillfully lashed together and the thatch was tied on by tied cords made from coconut sennit, ‘ie‘ie vine rootlets, or ukiuki. While nails were not available to Native Hawaiians they would not have been preferably due to the moist climate of the islands, the lashing gave the frame a certain elasticity which enabled the Hale to withstand heavy wind and rain.[29]

Hawaiian Hales was built by the owner of the house and a few others from the village and every step of the building process, from the initial selection of the site to the final dedication of the finished house, required careful religious supervision.[30] Signs and omens were carefully observed and the completion of a new house was regarded as akin to the birth of a child.[31] Before the owner of the Hale could live in their house a final ceremony had to be performed in which a priest would trim a section of thatch above the doorway as a symbolic cutting of the piko (navel string) of the house.[32]

Native Hawaiians of high rank or position might have up to six houses or more included a chapel for his family gods (heiau), an eating house for men (mua), the women’s eating house (hale aina), the women’s workhouse (kua or kuku), the common sleeping house (noa), and a private retreat for women (pea). Canoes might be kept in sheds (halau wa‘a), and foodsheds or

[28] Bryan, E. H. “6. The Home.” Essay. In Ancient Hawaiian Life, 18–21. Honolulu, HI,, HI: Books about Hawaii, 1950
[29] Ibid
[30] Ibid
[31] Ibid
[32] Ibid

storehouses for farmers to store their goods (hale papaʻa or hale hoahu).[33] While a hundred years ago almost the entire population of Hawaiʻi lived in Hales, today the last ancient Hale is preserved at the Bishop Museum on the island of Oʻahu.[34]

2.2 Types of Hale

Before discussing the Hale Halawai, Hale Kuʻai, Hale Noa, and Hale Waʻa it is important to dive a bit deeper into the architectural nuances of Hawaiian Hales and the types of habitations Hawaiians created.

2.2.1 Hales without Walls

The simplest form of Hale consisted of a roof that was built directly on the ground instead of being propped up by vertical walls. These types of Hales required less material, labor, and skill.[35] Based on the prevalence of this style in early sketches it can be deduced that this type of Hale was used by commoners. These types of Hales are A-Frame structures and the framework consists of a vertical ridge post (pou hana) set in the middle of each end.[36] The ridge post supports the main ridgepole (kauhuhu) placed directly on their upper ends. Straight rafters (oʻa), with their lower ends imbedded in the ground, are then crossed in spaced pairs over the ridgepole and a second ridgepole (kaupaku ʻiole) is laid in the forks so framed.[37] Two gable posts (kauhana) are equally spaced on either side of the median ridge posts and their upper ends are cut obliquely to fit against the underside of the end rafters to which they are lashed.[38]

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[33] Bryan, E. H. "6. The Home." Essay. In Ancient Hawaiian Life, 18–21. Honolulu, HI,, HI: Books about Hawaii, 1950
[34] Ibid
[35] Ibid
[36] Ibid
[37] Ibid
[38] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003

These types of Hales were used to protect food, clothing from the elements and to sleep in during the wet and cold weather, however, most Native Hawaiians ate, slept, and lived in the open-air.[39]

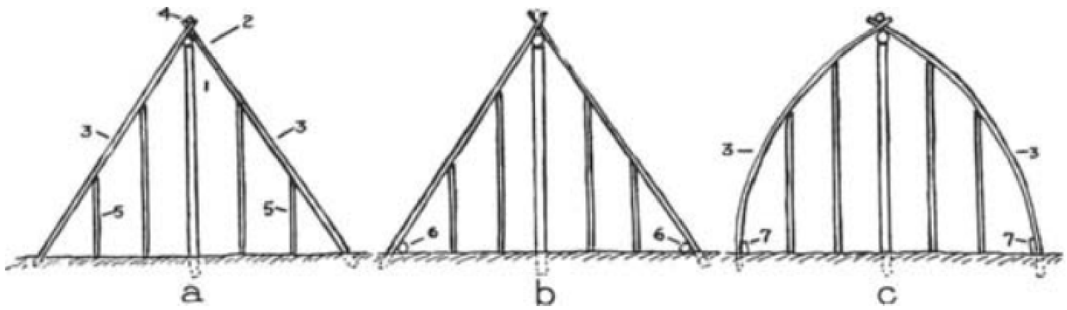

Figure 2. End Section of Houses Without Walls, Showing Ridge Post (11, Main Ridgepole (2), Rafters (3), Second Ridgepole (4), Gable Posts (5), Ground Plate Or Sill (61, and Vertical Stakes, or Ground Pegs (7) : A - Straight Rafters; B - Straight Rafters with Ground Plate or Sill; C - Curved Rafters (3) with Ground Pegs (7)

Source: Buck, 2003

2.2.2 Hales with Stone Walls

Areas of the island where loose pieces of stone were readily available, one way of clearing the area was to collect the stones and arrange them in a wall.[40] By arranging four walls in a rectangle of convenient size, it was an easy matter to place a roof on the walls instead of on the ground. The lower ends of the rafters could be readily fitted in on the side walls without creating any further problems in construction. As far as the structure was concerned, they occupied an intermediate position between the house without walls and the house with wooden walls thatched with grass.[41]

[39] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003.
[40] Ibid
[41] Ibid

2.2.3 Gable Roof with Thatched Walls

From historic sketches, it is evident that houses with gabled roofs were the type in general use during the late 1700s.[42] In this type of house, the elevation of the roof by means of vertical wooden walls resulted in some interesting local development in construction.[43] Scholars today have a good understanding with regards to native names of the parts of the framework and the order in which they were erected, but details of how the parts were lashed together and how the ridged bonnet was thatched are lacking.[44] Such technical details cannot be adequately described in print without accompanying line drawings, but Polynesian craftspeople taught their traditions orally, but thanks to the conservation of this cultural heritage many examples of this type of Hale can be found in museums and protected lands throughout the Hawaiian Islands.

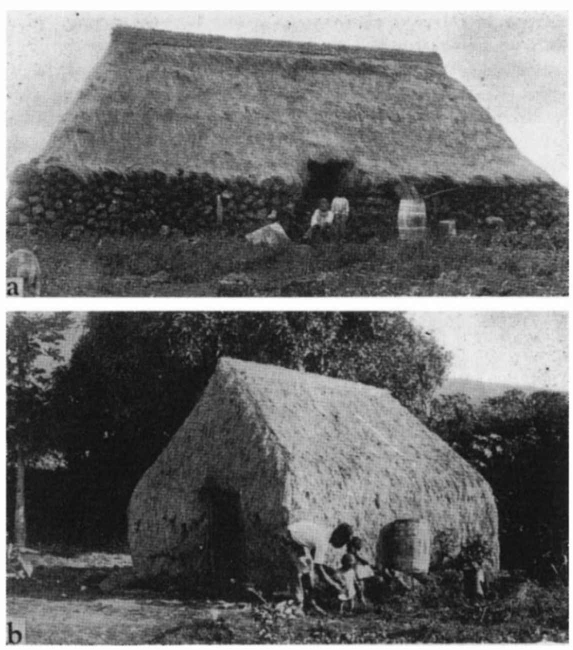

Figure 3. A - House with Stone Walls and Hipped roof ; B – House with Gabled Roof

Source: Buck, 2003

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[42] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003

[43] Ibid

[44] Ibid

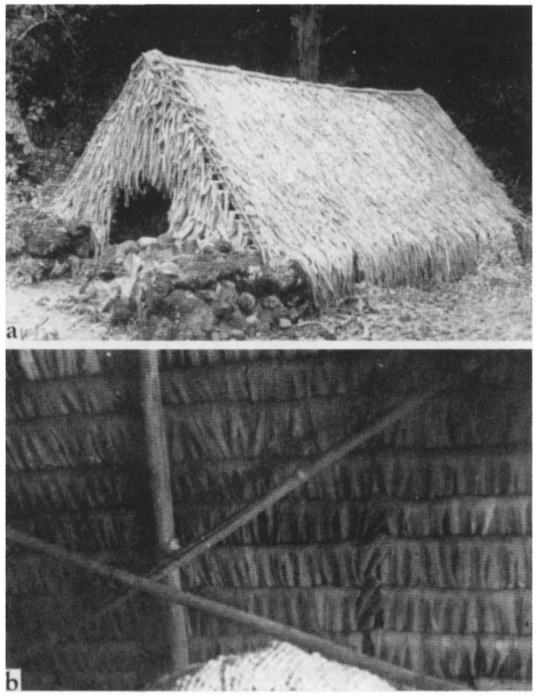

Figure 4. Fisherman's House, with Stone Walls and abled Ends

Source: Buck, 2003

2.2.4 Wooden Framework

Posts in the average Hales were three to four feet high in smaller variations and twelve to fourteen feet in the larger variations.[45] However, in the chief's houses, the posts were trimmed smoothly in the round. The thickness of the posts varied with the size of the house.[46] The upper ends of the corner and wall posts were cut to create a square notch that opened laterally and had additional cuts on the upper end.[47]

[45] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003

[46] Ibid

[47] Ibid

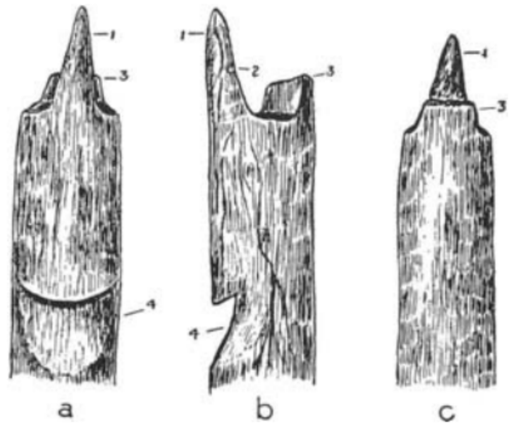

Figure 5. Upper End of Wall Posts, Showing (1) Tenon, (2) Upper Notch for Wall

Source: Buck, 2003

Into the four corner posts of the rectangular ground plan were tamped gravel and stones to make them firm. A rope was then stretched taut between the back corner posts and tied to their notches as another rope was stretched between them near their lower ends.[48]

Wall plates were formed of poles usually a little more than two inches in diameter, with the ark left on in the average house. They were placed in the notches of the two rows of posts and protruded at each end beyond the corner posts to furnish support for the gable plates.[49]

[48] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003

[49] Ibid

The lashing of the wall plate to the wall posts differed from the usual technique prevailing in Polynesia, owing to the extra provision of the ‘auwae notches on the outer side of the posts.[50] However, the ornamental patterns developed by the crossing on the inner side of the posts were similar to those used on the inner side of the wall posts of Samoan houses erected today.[51] The lashing material consisted of three-play braids made of ‘uki‘uki grass, sometimes coconut husk fiber or ‘ie ‘ie.

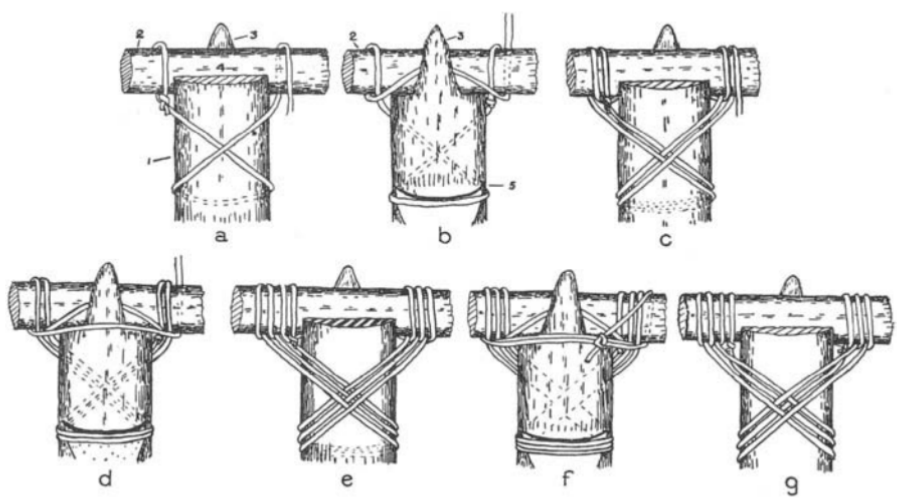

Figure 6. Lashing of Wall Plate to Wall Post

Source: Buck, 2003

The ridge posts were erected in the middle of the two ends, the midpoint between the back and the front corner posts being decided by stretching a cord between them and doubling it to get the half-length.[52] The height of the ridge posts determined the height of the house. In addition, the height, like the size, depended upon the social position of the owners. The ridge post name, pou hana, was used as a figure of speech to denote persons of importance as it

[50] Buck, Peter Henry. “II: Houses.” Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003
[51] Ibid
[52] Ibid

seemed that extra importance has been attributed to the post itself, for it stands somewhat aloof from the other posts.[53]

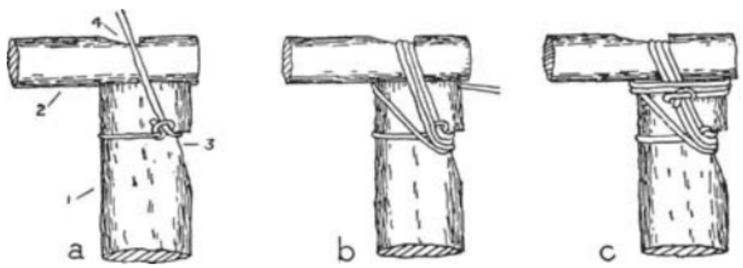

Figure 7. Lashing of Ridgepole to Ridge Post, Showing (1) Ridge Post, (2) Ridgepole (3) Ridge-Post Notch, (4) Ridgepole Notch: A - Commencement; B - Oblique Turns; C - Horizontal Turns and Fixation.

Source: Buck, 2003

2.2.5 Hipped-Roof Hale

The hipped roof differs from the gable roof in that the triangular part of the ends above the wall plate slopes inward and upward instead of being vertical.[54] This triangular part of the gable roof forms the upper part of the end wall, but in the hipped-roof house, it becomes part of the room. In the gable roof, the ridgepole is the same length as the house, but in the hipped roof, the ridgepole is shortened at each end.[55]

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[53] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003
[54] Ibid
[55] Ibid

Figure 8. House with a Hipped Roof

Source: Buck, 2003

This type of hale was not seen in any sketches made by early colonizers of the Hawaiian or in any ancient oral traditions, so it can be extrapolated that this type of hale was not used until after European colonization. The hale is comprised of a front wall that has a door opening, six wall posts, and a rear wall that has a similar number of posts opposite those in the front wall.[56]

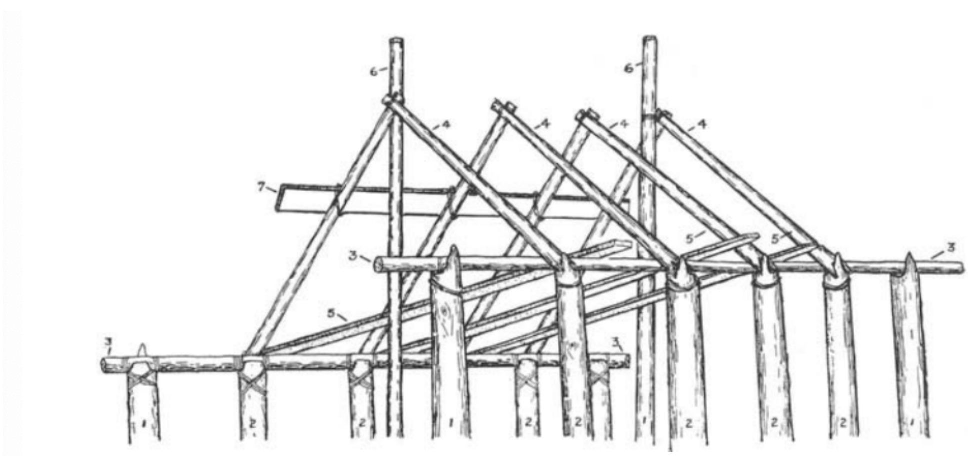

Figure 9. Erection of Rafters for Hipped Roof, Showing (1) Corner Posts, (2) Wall Posts, (3) Wall Plate, (4) Main Rafters, (5) Scaffold Planks, (6) Temporary Uprights, (7) Horizontal Strut.

Source: Buck, 2003

[56] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003

2.2.5 House on Piles

This sketch shows two houses with the floor raised above the surface of the ground (Figure 10). The framework of these houses was constructed in the same way as gable houses with walls. The very high roofs were thatched, but the walls were left bare.[57] These houses were built on the banks of the Waimea River and were on piles as a safeguard against floods.[58] However, after American colonization raised floors became popular as the space below could be used as a basement room that was much cooler than the rooms above.[59]

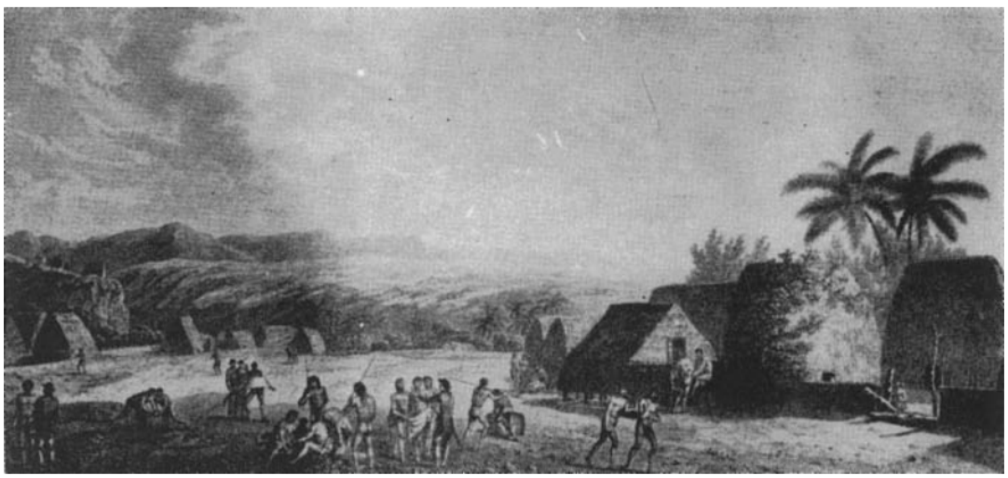

Figure 10. Drawing of Waimea, Showing Houses

Source: Buck, 2003

[57] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003

[58] Ibid

[59] Ibid

2.2.5 Thatching

The Hawaiian technique of thatching differed from that of central and western Polynesia due to the bunches of thatch that were tied to horizontal purlins on both the walls and the roof.[60] Hawaiians preferred to use pili grass for their thatching materials because of its color and fragrance when freshly cut.[61] Thatching ako was started on the front wall with the tip ends of the bundle pushed well down against the stone platform, then a braid of ‘uki ‘uki grass was used on the framework to bind the bundles of grass to the thatch purlins.[62] The braid was then tied to the left end of the second thatch purlin from the floor, and a large bunch of pili grass was laid vertically against the purlins as the braid was passed over the outer surface of the bunch toward the right then looped over the purlin, then finally hitched over itself with a couple of twists.

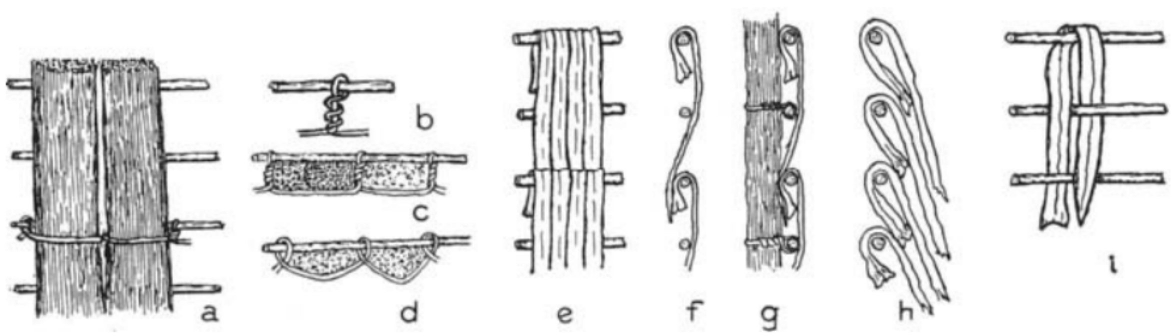

Figure 11. Thatching: A - Binding Pili Grass Bundles to Purlin; B - Detail of Braid Twist; C, D, Cross Section; E-H, Pandanus Thatching Technique; I - Ti-leaf Thatching Technique.

Source: Buck, 2003

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[60] Buck, Peter Henry. “II: Houses.” Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003

[61] Ibid

[62] Ibid

2.3 Four Main Hale

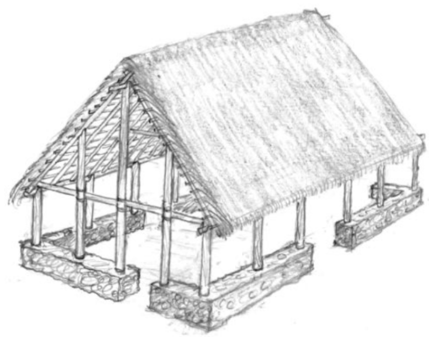
As was shown in the before-mentioned sections there are many styles of Hales. However, the main focus of this project will look at Hale Halawai, Hale Ku'ai, Hale Noa, and Hale Wa'a, which each have a unique structure and function.

ALLOWABLE USES FOR EACH HALE TYPE			
Hale Halawai	Hale Kuai	Hale Noa	Hale Waa
eating (ai)	eating (ai)		eating (ai)
assembling (halawai)	assembling (halawai)		assembling (halawai)
		sleeping (moe)	
retailing (e.g., fruits) (ku`ai)	retailing (e.g., fruits) (ku`ai)		retailing (e.g., fruits) (ku`ai)
	storage (papa`a)		storage (e.g., canoe) (papa`a)

Figure 12. Chart of Hale Styles and their Uses

Source: Article 12. Indigenous Hawaiian Architecture." honolulu.gov. City and County of Honolulu, , 2021.

The *Hale Halawai* may be open or thatched and is used for eating, assembling, and retail.



HALE HALAWAI
Open End Style

HALE HALAWAI
Thatched End Style

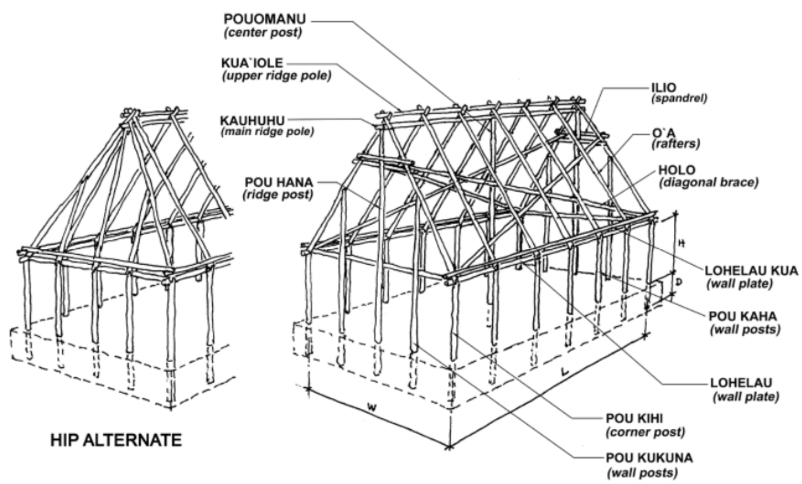


Figure 13. Diagram of Hale Halawai Open End Style and Closed End Stylr with Framework

Source: Article 12. Indigenous Hawaiian Architecture." honolulu.gov. City and County of Honolulu, , 2021.

The *Hale Ku'ai* is either a shed style or gable style and can be used for eating, assembly, retail, and storage.

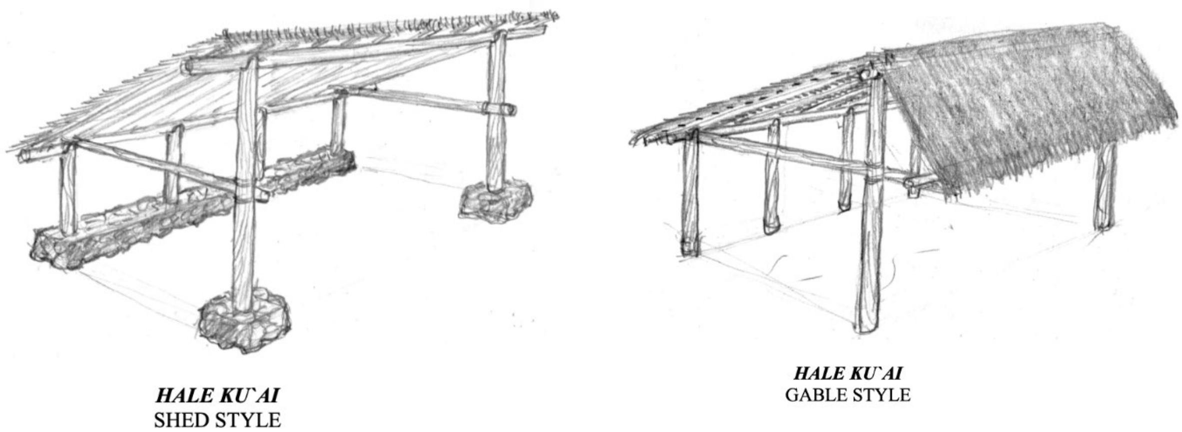


Figure 14. Diagram of Hale Ku'ai Shed Style and Gable Style

Source: Article 12. Indigenous Hawaiian Architecture." honolulu.gov. City and County of Honolulu, , 2021.

The *Hale Noa* is a slightly elevated Hale that is only used for sleeping. This type of Hale has at least two openings one of which is around three feet wide and five feet high and another opening that is around two feet wide and three feet high.[63]

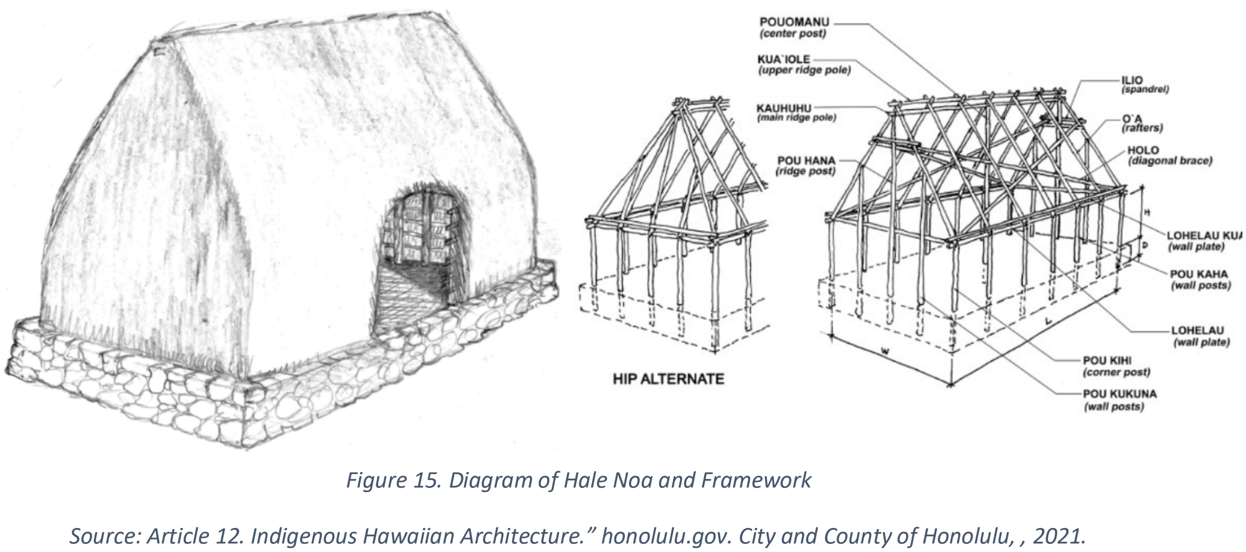


Figure 15. Diagram of Hale Noa and Framework

Source: Article 12. Indigenous Hawaiian Architecture." honolulu.gov. City and County of Honolulu, , 2021.

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[63] Buck, Peter Henry. "II: Houses." Essay. In Arts and Crafts of Hawaii, 75–110. Honolulu, HI: Bishop Museum Press, 2003

The *Hale Wa'a* is an A-frame style Hale that was used for eating, storage, retailing and assembly.

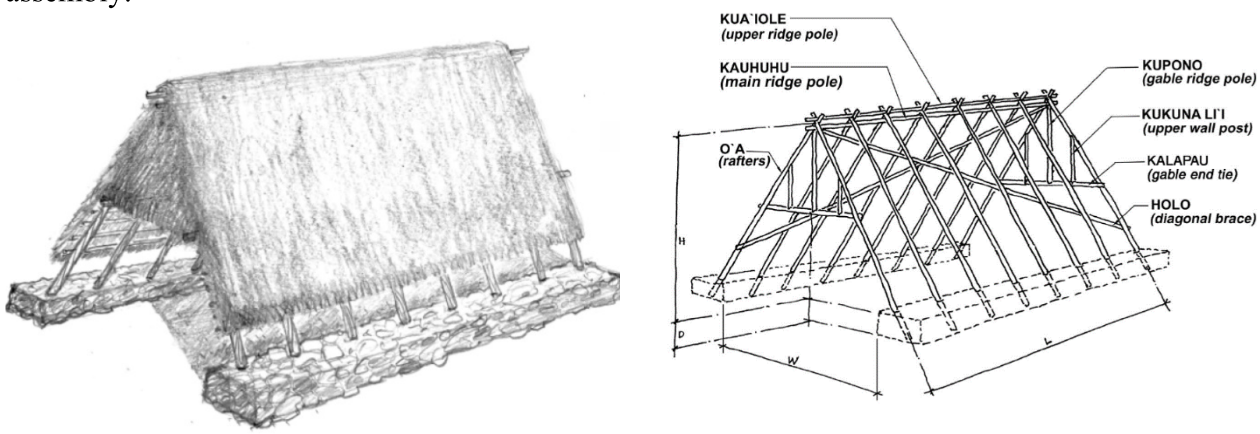

Figure 16. Diagram of Hale Wa'a and Framework

Source: Article 12. Indigenous Hawaiian Architecture." honolulu.gov. City and County of Honolulu, , 2021.

Chapter 3: Fabricating a Digital Reality

3.1 Types of Reality

Digital Reality is a term used to describe different computer-generated realities that users can interact and immerse themselves in. The most commonly used name to describe Digital Reality is the name Extended Reality (XR). Extended reality is an umbrella term for technologies like virtual reality (VR), augmented reality (AR) and mixed reality (MR). At present, XR covers the entire range of real and virtual environments.[64]

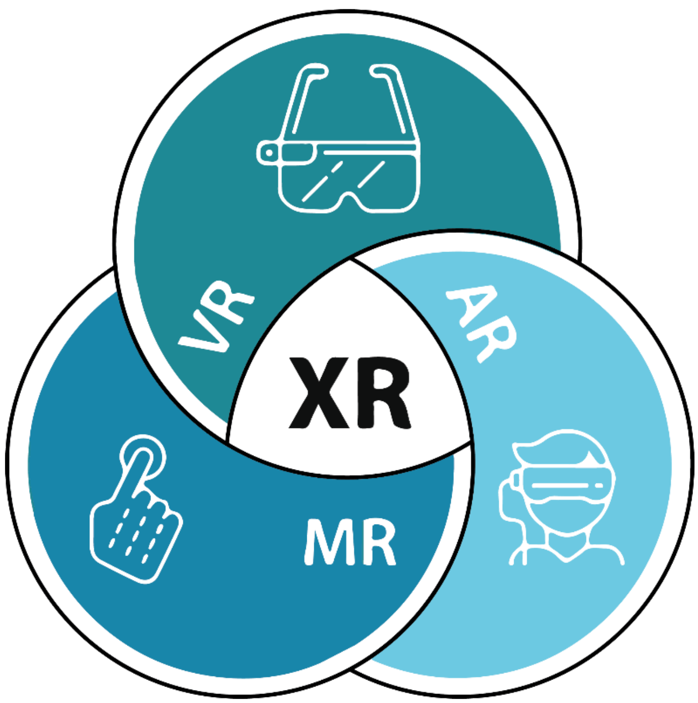

Figure 17. Extended Reality Umbrella

Source: Kaplan et el., 2020

[64] Kaplan, Alexandra D., Jessica Cruit, Mica Endsley, Suzanne M. Beers, Ben D. Sawyer, and P. A. Hancock. "The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis." Human Factors: The Journal of the Human Factors and Ergonomics Society 63, no. 4 (2020): 706–26. https://doi.org/10.1177/0018720820904229.

3.1.1 Virtual Reality

Virtual Reality (VR) is the use of computer technology to create a simulated environment. Unlike traditional user interfaces, VR places the user inside an experience for full immersion. Instead of viewing a screen in front of them, users are immersed and able to interact with 3D worlds. By simulating as many senses as possible, such as vision, hearing, touch, even smell, the computer is transformed into a gatekeeper to this artificial world.[65] The only limits to near-real VR experiences are the availability of content and cheap computing power.[66]

Virtual Reality's most recognizable component is the head-mounted display (HMD). Humans are visual creatures, and display technology is one of the single biggest differences between immersive VR systems and traditional user interfaces like watching tv. While there are a wide variety of hardware and software options for using VR immersive technologies HMD's are one of the best options and will be used in this dissertation project.

3.1.2 Augmented Reality

Augmented reality (AR) is one of the classes of digital reality that spans from the real environment and ends with the virtual environment.[67] Anything in between is a possible composition of real and virtual objects. An AR system is an interactive system that runs in real time and displays virtual objects contextually aligned with the real world.[68] AR environments employ two distinct types of data overlay, marker-based and global positioning. Marker-based

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[65] Kaplan, Alexandra D., Jessica Cruit, Mica Endsley, Suzanne M. Beers, Ben D. Sawyer, and P. A. Hancock. "The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis." Human Factors: The Journal of the Human Factors and Ergonomics Society 63, no. 4 (2020): 706–26. https://doi.org/10.1177/0018720820904229.

[66] Ibid

[67] Ashour, Ziad, and Wei Yan. "BIM-Powered Augmented Reality for Advancing Human-Building Interaction." Cumincad, ECAADe, 2020, papers.cumincad.org/cgi-bin/works/paper/ecaade2020_499

[68] Ibid

environments employ distinct markers and images to locate virtual data within the physical world.[69] The second is associated with smart device augmented reality and involves GPS, digital compass, and accelerometer sensors to position users and the virtual content around them. Tracking the real-world environment and registering virtual information in a real-world environment are core functions of an AR system.[70] Aside from data overlay, there are methods that can be classified for tracking such as:

1) vision-based
2) sensor-based
3) hybrid based

Vision-based tracking can be further separated into two sub-classes: marker-based and marker-less methods.[71] Marker-based utilizes 2D images, such as QR code markers, which the AR system detects to enable a device to determine its relative position and orientation to the marker and then project the virtual model according to the location of that marker in the real world and its reference in the virtual world.[72] Marker-based methods could be beneficial for specific applications; however, they are not suitable in real-life scenarios, such as on construction and operational sites, because marker detection might be disturbed by people, furniture, tools and machinery.[73] The second sub-class takes advantage of computer vision to spatially understand the real-world context in order to correctly register virtual information in the real world.[74] Sensor-based tracking methods employ different technologies, such as GPS,

[69] Ashour, Ziad, and Wei Yan. "BIM-Powered Augmented Reality for Advancing Human-Building Interaction." Cumincad, ECAADe, 2020, papers.cumincad.org/cgi-bin/works/paper/ecaade2020_499
[70] Ibid
[71] Ibid
[72] Ibid
[73] Ibid
[74] Ibid

Bluetooth, ultrawideband (UWB), Wi-Fi, radio frequency identification (RFID) and inertial sensors.[75]

Hybrid tracking combines multiple tracking methods, for example vision- and sensor-based methods. For example, InfoSPOT is an AR system that utilizes a marker-based method for device calibration, combined with sensor-based methods, including Wi-Fi, digital compasses, three-axis gyroscopes and accelerometers, to align virtual models and labels with the physical world.[76]

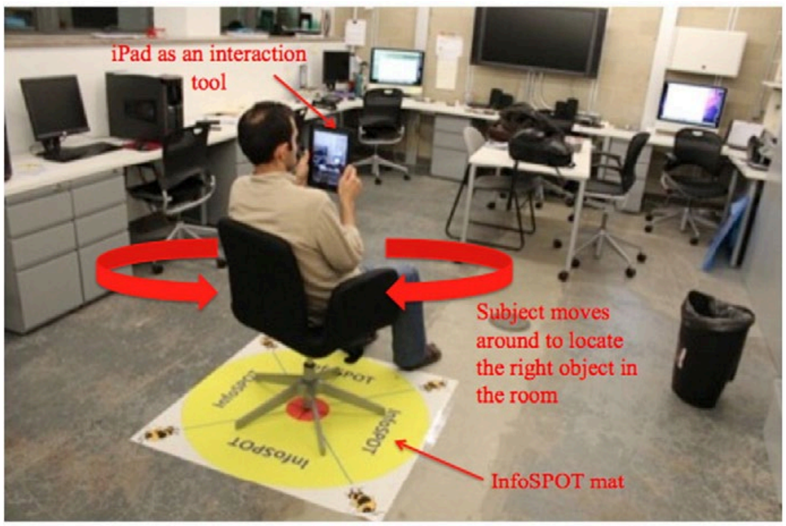

Figure 18. InfoSPOT Experiment Setup

Source: Irizarry et al., 2013

[75] Ashour, Ziad, and Wei Yan. "BIM-Powered Augmented Reality for Advancing Human-Building Interaction." Cumincad, ECAADe, 2020, papers.cumincad.org/cgi-bin/works/paper/ecaade2020_499

[76] Irizarry, Javier, Masoud Gheisari, Graceline Williams, and Bruce N. Walker. "InfoSPOT: A Mobile Augmented Reality Method for Accessing Building Information through a Situation Awareness Approach." Automation in Construction 33 (August 1, 2013): 11–23. https://doi.org/10.1016/j.autcon.2012.09.002.

However, this method might be limited to few applications, since it requires a user to be situated in a specific location in the middle of the room after calibrating the device using a marker (Figure 18).[77]

AR based applications provide an opportunity to reconnect and better realign virtual and physical worlds through location awareness, enhanced data overlays, and user-focused content.[78] Unlike more static forms of digital media, augmented reality, with its interactive and context aware functionalities, engages users in more direct and meaningful ways. This is evident not only in academia, but also in commerce and advertising. The interactive print approach popularized by AR Lego models are associated with mainstream toy products and are successful because they extend the level of consumer engagement. They provide additional information and enticement for consumers. The same lessons of consumer engagement are directly applicable to design education and design services.

[77] Irizarry, Javier, Masoud Gheisari, Graceline Williams, and Bruce N. Walker. "InfoSPOT: A Mobile Augmented Reality Method for Accessing Building Information through a Situation Awareness Approach." Automation in Construction 33 (August 1, 2013): 11–23. https://doi.org/10.1016/j.autcon.2012.09.002.

[78] Kaplan, Alexandra D., Jessica Cruit, Mica Endsley, Suzanne M. Beers, Ben D. Sawyer, and P. A. Hancock. "The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis." Human Factors: The Journal of the Human Factors and Ergonomics Society 63, no. 4 (2020): 706–26. https://doi.org/10.1177/0018720820904229.

3.1.3 Mixed Reality

MR is a step beyond Augmented Reality, in which additional information is added to that which a user perceives. In MR, the physical and virtual worlds interact, and users can interact with them as well. Holographic devices create digital objects and place them in a real environment, so they appear to really be there.[79] Immersive devices, in contrast, help conceal elements of the physical world and replace them with digital creations.[80] An HMD can utilize a see-through display with digital content projected onto it. An immersive headset, like VR goggles, may actually block a user's view of the physical world, so that the user can only see the digital one.

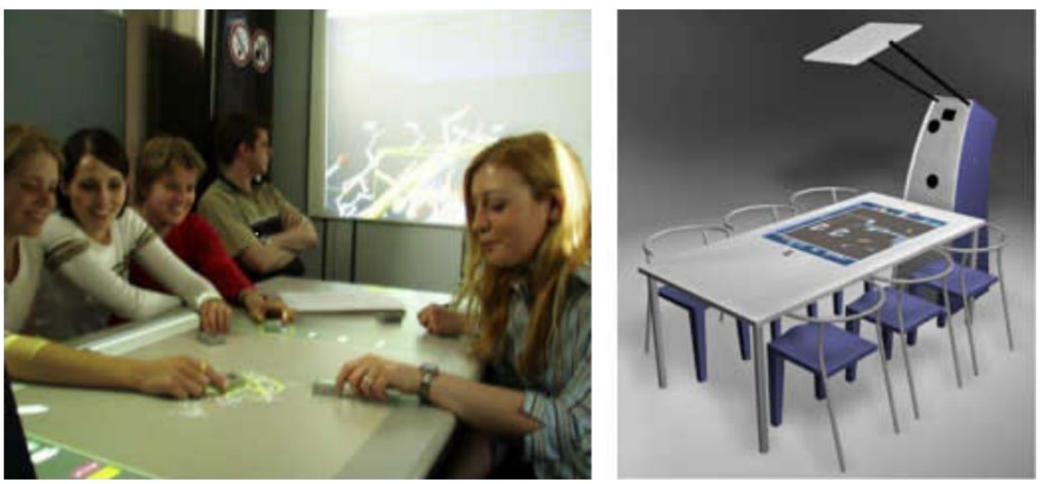

Figure 19.The BUILD-IT System, an Example of a Collaborative Tabletop MR Application

Source: Costanza et al., 2009

MR systems are designed to give their users the illusion that digital objects are in the same space as physical ones (Figure 19). For this illusion of coexistence, the digital objects need

[79] Kaplan, Alexandra D., Jessica Cruit, Mica Endsley, Suzanne M. Beers, Ben D. Sawyer, and P. A. Hancock. "The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis." Human Factors: The Journal of the Human Factors and Ergonomics Society 63, no. 4 (2020): 706–26. https://doi.org/10.1177/0018720820904229
[80] Ibid

to be precisely positioned into the real environment and aligned with the real objects in real time.[81]

3.2 Intended uses in Architecture

3.2.1 Interior

Research that examines virtual furniture and adjustments turn to design methods by using Augmented Reality for interior design education. In an AR environment, design work can become more lively, convenient, and intelligent. Plus, design work and manufacturing can be conducted at the same time with each other.[82] With AR, the virtual products or graphic technology are not only for simulation but can also be used to obtain practical higher values when it comes to designing furniture.[83] Virtual furniture can be moved, resized, and rotated, then placed in the location of where it would sit in the real environment.[84] Furthermore, AR technology can be an animated simulation tool for interior design, allowing the user to see a mixed AR scene through HMD or video display.[85] Also, the interactive potential can be increased according to the user's needs. All of which allows for better communication between designer and client.

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[81] Costanza, Enrico, Andreas Kunz, and Morten Fjeld. "Mixed Reality: A Survey." Lecture Notes in Computer Science, March 27, 2009, 47–68. https://doi.org/10.1007/978-3-642-00437-7_3
[82] Choo, Seung Yeon, et al. "Augmented Reality- Effective Assistance for Interior Design: Focus on Tangible AR Study." Cumincad, ECAADe, 2009, papers.cumincad.org/cgi-bin/works/paper/ecaade2009_002
[83] Ibid
[84] Bahri, Haythem, et al. "Efficient Use of Mixed Reality for BIM System Using Microsoft HoloLens." IFAC-PapersOnLine, vol. 52, no. 27, 2019, pp. 235–239., doi:10.1016/j.ifacol.2019.12.762
[85] Choo, Seung Yeon, et al. "Augmented Reality- Effective Assistance for Interior Design: Focus on Tangible AR Study." Cumincad, ECAADe, 2009, papers.cumincad.org/cgi-bin/works/paper/ecaade2009_002

3.2.2 Urban Planning

Augmented Reality systems can integrate real and virtual worlds for outdoor sustainability education. Mobile augmented reality technology is simple enough to quickly view newly constructed urban structures. Users can virtually see the underlying structural systems outdoors and map the virtual objects to physical reality through embodied interaction with the computational device.[86] The objective for urban use of AR is to make invisible information visible to users and to extend interactions with the "living" environment.[87] Additionally it is important to create a burden-free environment and to provide a computer-generated representation of reality in real time.[88] For future uses, being able to compose a video of the real world and the panoramic virtual model of underlying infrastructure outdoors would allow multi-users to interact with mixed reality in an intuitive manner beyond the viewing window of augmented reality.[89]

3.2.3 Assembly Fabrication

Many uses for AR involve the integration of holographic assembly. Most projects that research the degree of satisfaction and integration utilize visual technologies associated with mobile devices in the process of architectural design.[90] The translation from the digital to the physical when a definite materiality appears during the digital fabrication process is crucial and it

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[86] Kuo, Chyi-Gang, et al. "Mobile Augmented Reality for Spatial Information Exploration." Cumincad, CAADRIA, 2004, papers.cumincad.org/cgi-bin/works/paper/512caadria2004

[87] Ibid

[88] Ibid

[89] Ibid

[90] Redondo, Ernest, et al. "Augmented Reality in Architecture Degree New Approaches in Scene Illumination and User Evaluation." Academia.edu, Journal of Information Technology and Application in Education, 2012, www.academia.edu/27428447/Augmented_Reality_in_Architecture_Degree_New_Approaches_in_Scene_Illumina tion_and_User_Evaluation

is typically approached as a linear and predetermined sequence.[91] This step offers the potential of embedding a certain level of interactivity between the fabricator and the materialized model during the fabrication process to allow for real time adjustments or corrections.[92]

3.2.4 Technical Issues

There are multiple emerging interactive technologies that are adopted by designers and extended into areas of design, education, entertainment, and commerce. AR-based applications increasingly occupy an important place in branding/marketing, tourism, education, and many other parts of life.[93] AR has brought the virtual and the physical world closer and made them highly interconnected and interdependent through location awareness, enhanced data overlays, and user-focused content. It also finds its applications in a diverse range of disciplines and a number of the AR applications discussed in this research exemplify an idea of "learning anytime, anywhere".[94] It allows for passive as well as active interaction with information and virtual content. Users can visually experience static information and to interact with data in more dynamic and speculative ways.[95] By merging computer-generated learning materials and stimuli of virtuality into a real space different cognitive and social-learning processes might involve unique learning activities that can be potentially supported by separate technological modes of tangible AR.[96]

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[91] Chaltiel, Stephanie, et al. "Digital Fabrication with Virtual and Augmented Reality for Monolithic Shells." Cumincad, ECAADe, 2017, papers.cumincad.org/cgi-bin/works/Show?ecaade2017_244

[92] Ibid

[93] Andrzej, Zarzycki. "Teaching and Designing for Augmented Reality." Cumincad, ECAADe, 2014, papers.cumincad.org/cgi-bin/works/paper/ecaade2014_162.

[94] Ibid

[95] Ibid

[96] Chen, Rui, and Wang Xiangyu . "Tangible Augmented Reality for Design Learning: An Implementation Framework." Cumincad, CAADRIA, 2008, papers.cumincad.org/cgi-bin/works/paper/caadria2008_43_session4b_350

3.3 Benefits of Smart Device Augmented Reality (SDAR)

Through the years, augmented reality has become more accessible to users which can be seen as something that has become integrated almost seamlessly with our everyday lives.[97] Most augmented reality features come as a standard with phones and tablets that require no additional installation. Most operating systems use the phone camera applications to utilize AR to focus camera views or where to point the camera display for the "best photo" shot. Many other applications involve the use of phone games that track through GPS or Bluetooth tracking, such as PokemonGo. Smart devices are widely accessible to users due to tablets and phones being an immediate necessity for most people. When using AR through a smart device designers can provide real time design solutions because most devices have operating systems that are powerful enough to overlay digital content on top of physical elements.[98]

3.4 Benefits of Head Mounted Display (HMD)

A head mounted display (HMD) is a device that provides immersion to digital realities that differs from using a smart device. A common HMD among users is the Microsoft HoloLens, which is a head-mounted Windows 10 device (figure 20). The display is a translucent visor-based system, allowing the user to view both real and virtual worlds (figure 21). Interaction is via gaze, gesture and voice inputs or, optionally, wireless peripherals. In a paper written by Paul Hocket on the HoloLens and augmented reality, Paul notes that the user large scale visualization

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[97] Craig, Alan B. "Mobile Augmented Reality." Understanding Augmented Reality, 2013, 209–20. https://doi.org/10.1016/b978-0-240-82408-6.00007-2.
[98] Ibid

pushes the capabilities of the HoloLens. In the cases that, two aspects of the hardware are quite apparent to the user during the experience.[99]

Figure 21. The Microsoft HoloLens for AR/MR

Source: Hockett et al., 2016

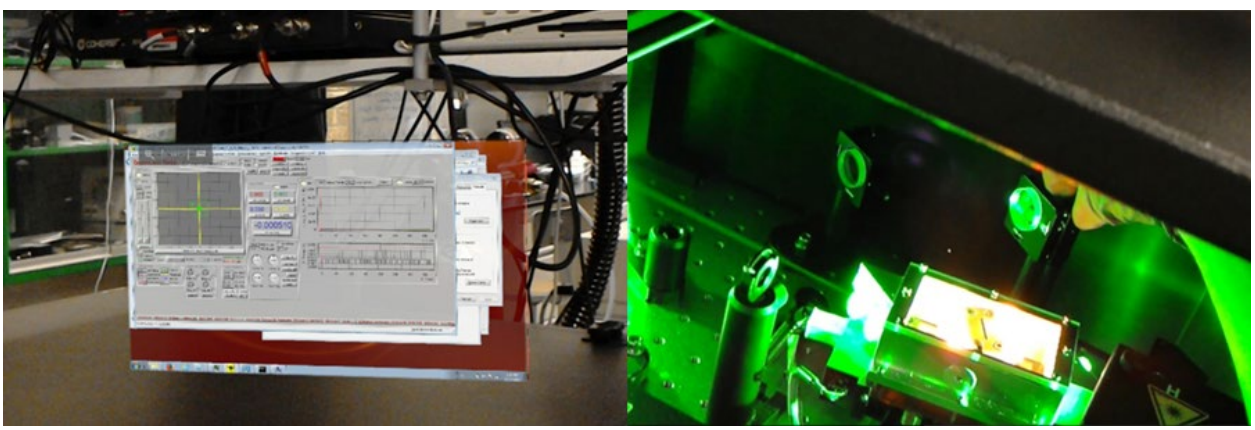

Figure 20. MR Environment from the User PoV

Source: Hockett et al., 2016

[99] Hockett, Paul, and Tim Ingleby. "Augmented Reality with Hololens: Experiential Architectures Embedded in the Real World." Authorea, Oct. 2016, doi:10.22541/au.148821660.05483993.

1) The spatial position of the 3D object fluctuates somewhat.
2) The field of view of the Hololens (which does not fill the user's peripheral vision) is quite apparent for large objects.

However, neither issue is major and, given the impressive spatial mapping of the platform, in the worst case, these aspects may take the user out of the immersive experience.[100] These issues are minor in general usage especially when visualizing objects at smaller scales or using Hololens based Windows applications (essentially 2D virtual screens placed in the environment).

[100] Hockett, Paul, and Tim Ingleby. "Augmented Reality with Hololens: Experiential Architectures Embedded in the Real World." Authorea, Oct. 2016, doi:10.22541/au.148821660.05483993.

Chapter 4: Case Studies

4.1 Remodel of Gensler Los Angeles Office

This project located in Los Angeles, California, was completed by the Gensler LA Office and shows how Augmented Reality can be used in construction. The project involved creating the remodeled Gensler Los Angeles office. Gensler used mixed reality to design and create a skybridge that internally connects the two existing Gensler buildings. The hardware and software made it possible to place a hologram of the proposed glass-encased bridge on the interior wall where they wanted to tear out and study the impact of the design. The skybridge was designed to contain flexible workspaces, wellness rooms and a patio.[101] Gensler explored the use of SketchUp viewer application on the Microsoft HoloLens to virtually experience and inhabit the sky bridge.[102]

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[101] Esser, Nick. "How Gensler Is Using Microsoft Hololens and Mixed Reality to Develop Its Projects." DRIVENxDESIGN. 2017 GOV Design Awards, June 26, 2017. https://drivenxdesign.com/gov17/news_details.asp?AssetId=43186.

[102] Ibid

Figure 22. Inside Gensler's Remodeled Los Angeles Office

Source: Esser., 2017

The designer's intention was to use this new technology to see if it would allow a more streamlined approach to building the skybridge. Additionally, they wanted to see if it would be more time effective and decrease problems with design and improve communication between architect and client.

The pros to doing the project was that it worked very well. As Alan Robles, Gensler's firmwide creative media leader stated, "We could evaluate the height of the bridge panels and decide if they aesthetically met our requirements and whether we saw any problems." He goes on to say that, "It allowed us to make better decisions on what the ultimate product would look like. One of the great things about being able to bring our design materials out of screen space and into real space is that we can interact with and evaluate our design product in context. That's really powerful."[103] Using the HoloLens allowed for better decision making on what the ultimate product would look like. Due to the ability to share the design on a screen space and how it would look in real space with the client in real time allowed for further communication with stakeholders. By being able to quickly draw up and modify any plans allowed the architects to better communicate an envisioned space to the clients before it existed. Alan Robles additionally quotes, "The client has been very, very engaged in using the latest technologies to make sure we're able to understand and communicate the impact of what the space is going to be."[104]

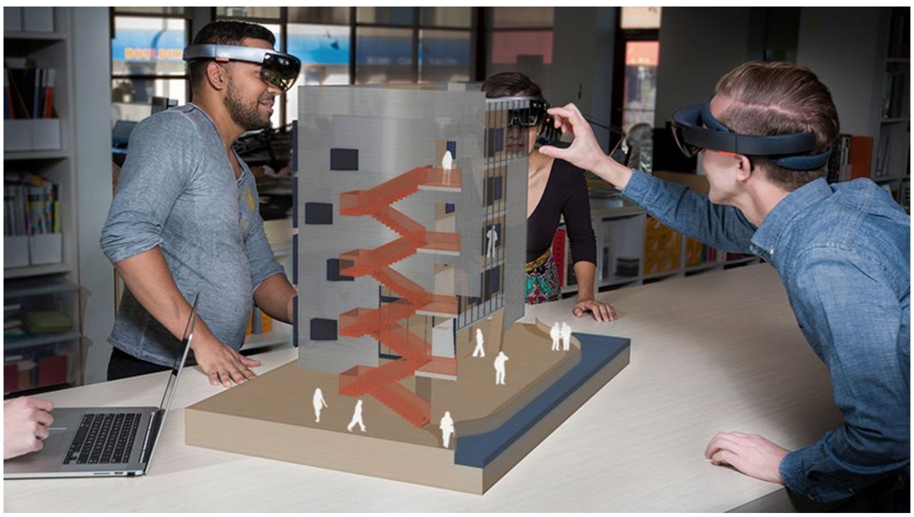

Figure 23. Gensler Using SketchUp Viewer on Microsoft HoloLens

Source: Esser., 2017

While there were little implications mentioned in the article of the project, there are some issues that come with using holographic assembly with a Head Mounted Display that can be extrapolated by other research conducted by this dissertation. Implications similar to dealing with how the opacity in which the hologram displays can make it difficult to see the overall hologram. By figuring out the settings for the best opacity, the users can spend a lot of time to

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[103] Esser, Nick. "How Gensler Is Using Microsoft Hololens and Mixed Reality to Develop Its Projects." DRIVENxDESIGN. 2017 GOV Design Awards, June 26, 2017. https://drivenxdesign.com/gov17/news_details.asp?AssetId=43186.
[104] Ibid

figure out the best settings and how that will correspond with that the actual design.[105] A current implication in using the HoloLens is the possible vision impairment users face when wearing the HMD. Users that have any vision impairment or the use of corrective lenses like glasses can find the device difficult to use due to the device being front heavy and not allowing much space for users that use glasses. Although this project gives a great example in how a firm or place of business can use a HMD device like the HoloLens, the price point is high for a single individual client/non-profit/or small business to utilize this technology for personal use.

In summary, this project serves as an example of how a Head Mounted Display can be used in creating holographic overlays to experiment different iterations in construction and renovation. The use of this technology really helps streamline the design processes and is useful in communication between clients and architects. It allows for real time collaboration, faster and fewer iterations of the design, and serves to help clients save time, money, and avoid frustration by using this technology.

4.2 Construction Assembly of Steel Woven Structures

This project was about constructing Steel Woven Structures through the use of a Head Mounted Display and assembly procedures. The project was conducted by Gwyllim Jahn, Cameron Newnham, Nicholas van den Berg, and Matthew Beanland. The authors write that due to the construction industry's reliance on two-dimensional documentation, results in inefficiency, inconsistency, waste, human error, increased costs, and limits architectural experimentation with

[105] Esser, Nick. "How Gensler Is Using Microsoft Hololens and Mixed Reality to Develop Its Projects." DRIVENxDESIGN. 2017 GOV Design Awards, June 26, 2017. https://drivenxdesign.com/gov17/news_details.asp?AssetId=43186.

novel form, structure, material, or fabrication approaches.[106] This project aimed to use a software platform that allowed designers to create interactive holographic instructions that translated a design model into an intelligent process rather than a static drawing. In addition, the fabrication also used mixed reality to demonstrate that unskilled construction teams could assemble a complex structure in a short time frame with minimal errors.[107]

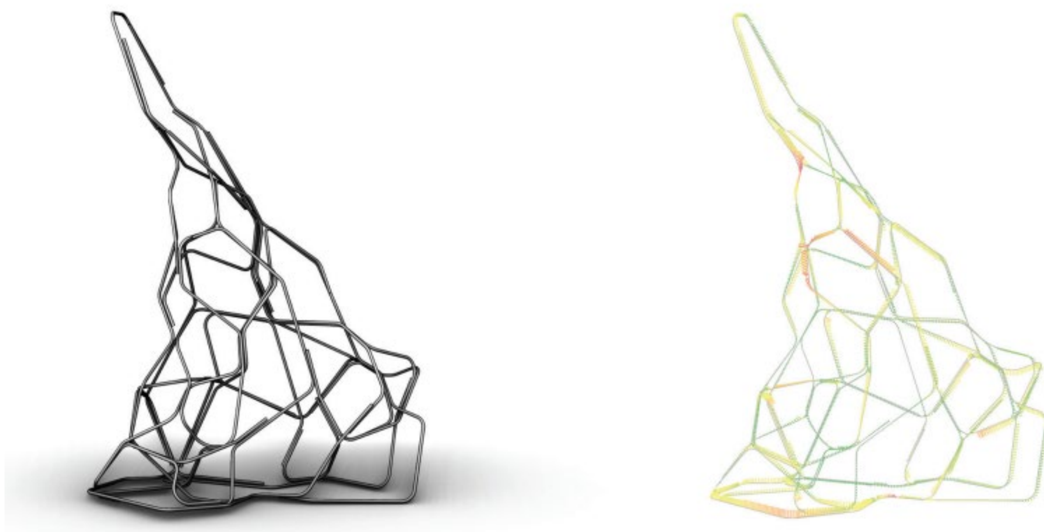

Figure 24. Proposed Digital Model and Sculpture

Source: Jahn, et al., 2018

The authors intention behind the Woven Structure was to use a system beyond the traditional two-dimensional documentation for a construction project and show how the use of mixed reality and software could improve construction project. The developed software platform that the authors used enabled the designers to rapidly prototype mixed reality applications directly within industry standard CAD tools, removing the requirement for programming,

[106] Jahn, Gwyllim, et al. "Making in Mixed Reality. Holographic Design, Fabrication, Assembly and Analysis of Woven Steel Structures." Cumincad, ACADIA, 2018, papers.cumincad.org/cgi-bin/works/BrowseTreefield=seriesorder=AZ/Show?acadia18_88
[107] Ibid

application development expertise, and enabling improvisation of task specific applications for design and construction.[108] This platform provides near real-time spatial and geometric information bidirectionally between the Microsoft HoloLens, Rhinoceros3D, and Grasshopper3D (figure 25).

Figure 25.Users Navigating Digital Pieces of the Structure for Fabrication

Source: Jahn, et al., 2018

Through the experiment, the authors found inaccuracies in segment lengths between bends that resulted in significant errors as the lengths of the pieces could not be adapted during assembly, but instead this led to cumulative errors across the structure. However, they did not observe this as a common cause of error in the design because registering the correct length of pipe using a holographic guide is a simple task working from only 1D information and is not

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[108] Jahn, Gwyllim, et al. "Making in Mixed Reality. Holographic Design, Fabrication, Assembly and Analysis of Woven Steel Structures." Cumincad, ACADIA, 2018, papers.cumincad.org/cgi-bin/works/BrowseTreefield=seriesorder=AZ/Show?acadia18_88

affected by occlusion of physical material by holographic information.[109] Additionally, inaccurate bend angles also resulted in errors during the assembly, but could be accounted for due to some flexibility in material.[110] Using a 3D holographic guide to accurately reproduce bend angles required significant skill, because even small errors in bend angles accumulate across the finished piece and results in deviations from the digital model (figure 26).[111]

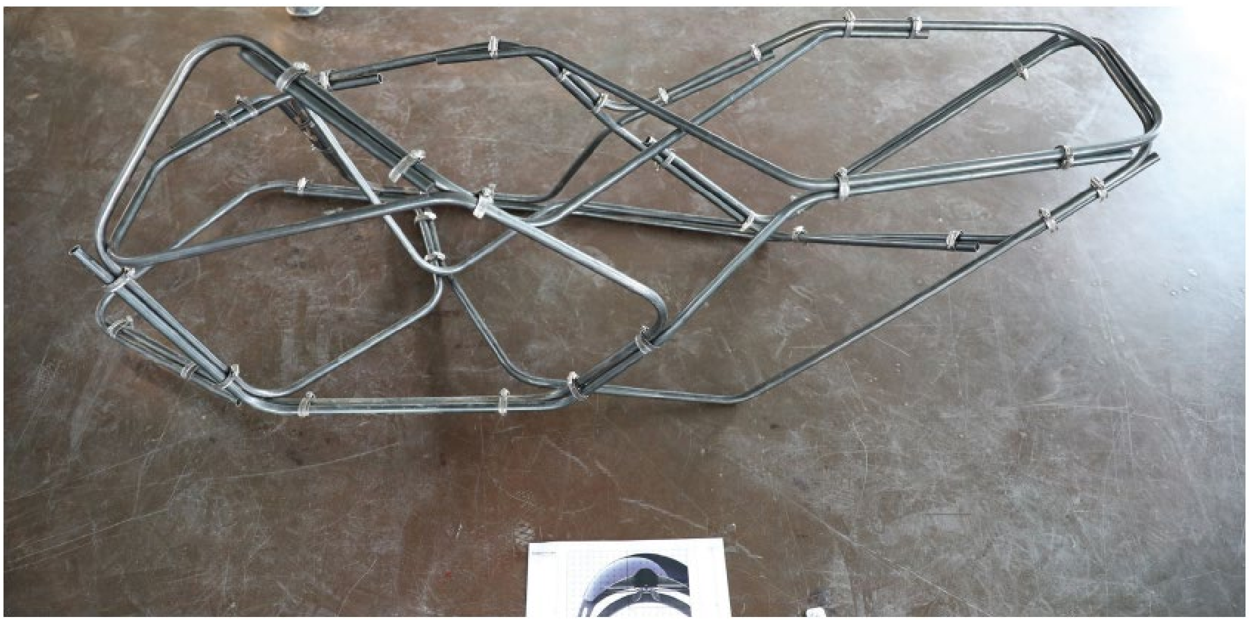

Figure 26. A Small Chunk of the Pavilion with Image Marker Used to Calibrate Digital and Physical Models During Digitization

Source: Jahn, et al., 2018

This research demonstrates what the current generation of head-mounted displays such as the HoloLens provide the user. With sufficient registration of holograms to physical environments in addition to using it as a reference for the accuracy of an assembly or fabrication

[109] Jahn, Gwyllim, et al. "Making in Mixed Reality. Holographic Design, Fabrication, Assembly and Analysis of Woven Steel Structures." Cumincad, ACADIA, 2018, papers.cumincad.org/cgi-bin/works/BrowseTreefield=seriesorder=AZ/Show?acadia18_88

[110] Ibid

[111] Ibid

task, the most deviation from digital models derived from lack of assembly experience rather than drift in the holographic reference model. The authors measure this using a method of digitizing the as-built structure using a marker tracking method that creates an accurate model from only a limited number of sample points for immediate feedback to designers and without the requirement for 3D scanning setups and mesh reconstruction software.

In summary, this research experiment tested out the application in which AR is used to create and assemble complex parts of a steel structure. The authors of the research explored ideas of that go beyond the traditional two-dimensional documentation for construction and show how successful the use of mixed reality and the software can be. In conducting the research, the authors found that the accuracy in creating some of the steel pieces to deviate from what the digital model had but overcame the errors due to the flexibility in the material being used. Keeping this in mind, it is useful to know that the physical piece can deviate from the digital model by small variations. This research gives a great example of how assembly and fabrication of a model can be completed through AR by users that have little to no background knowledge in construction.

4.3 Effectiveness of Augmented Reality

In the paper "*Comparative Effectiveness of Augmented Reality in Object Assembly*" authors Arthur Tang, Charles Owen, Frank Biocca, and Weimin Mou from Michigan State University ran an experiment that tested the relative effectiveness of AR instructions in an assembly task. The study aimed to provide three key contributions to understanding computer-human interaction with AR environments.[112]

[112] Tang, Arthur, et al. "Comparative Effectiveness of Augmented Reality in Object Assembly." Proceedings of the Conference on Human Factors in Computing Systems - CHI '03, Apr. 2003, doi:10.1145/642611.642626.

1) Does AR improve human performance in assembly tasks relative to other media?
2) What is a theoretical basis for how AR interfaces might provide cognitive support and augmentation?
3) Are there weaknesses in current AR interface design methodologies?

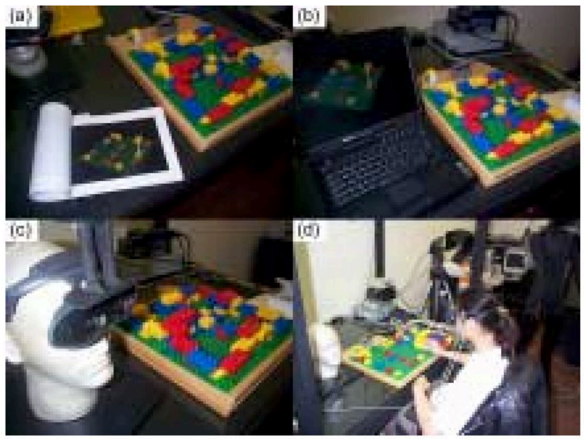

Figure 27. Experimental setups: (a) Treatment 1: Printed Media, (b) Treatment 2: CAI on LCD, (c) Treatment 3 and 4: CAI on HMD and AR, (d) Experiment in Action.

Source: Tang, et al., 2003

The authors write that the application of Augmented Reality in this experiment is determining an increase in productivity of manufacturing assembly, equipment maintenance, and procedural learning.[113] Making the purpose of this research project to explore the effectiveness of using Augmented Reality as an instructional medium in computer-assisted assembly. It is theorized that AR assistance in an assembly task will increase productivity and reduce errors due to the representation of the task registered with the workspace.[114] Three instructional medias were compared with the AR system. Results indicated that overlaying 3d instructions on the actual workpieces reduced the error rate for an assembly task by 82% indicating the decreased

[113] Tang, Arthur, et al. "Comparative Effectiveness of Augmented Reality in Object Assembly." Proceedings of the Conference on Human Factors in Computing Systems - CHI '03, Apr. 2003, doi:10.1145/642611.642626.
[114] Ibid

mental effort in the AR condition, which allows for some of the mental calculation of an assembly task to be offloaded by an AR system.[115]

The experiment involved used four different forms of instructional media (figure 27):

1) A printed manual. The printed manual was single sided, with one procedural step per page. The size of the diagrams were 8.5” x 6”. Additionally, the subjects were free to move the manual to anywhere in the workspace or hold it in their hand during operation.
2) Computer Assisted Instruction (CAI) on an LCD monitor. Instructions were displayed in full screen on a laptop computer placed on the workspace. The size of the LCD monitor was 15”. Before the start of the experiment, subjects were free to adjust the brightness, position and orientation of the screen.
3) CAI on a see-through HMD. Instructions were displayed on a see-through HMD. It simulated a 30-inch diagonal screen at a viewing distance of 4 feet ahead.
4) A spatially registered Augmented Reality. Instructions were displayed though a HMD. Subject head motion was tracked through the experiment and stereo graphics were rendered in real time based on the data from the tracker.

This experiment benefits from the evidence it produces to support the proposition that AR systems improve task performance and can relieve mental workload on assembly tasks. The ability to overlay and register information on the workspace in a spatially meaningful way allows AR to be a more effective instructional medium.

[115] Tang, Arthur, et al. “Comparative Effectiveness of Augmented Reality in Object Assembly.” Proceedings of the Conference on Human Factors in Computing Systems - CHI '03, Apr. 2003, doi:10.1145/642611.642626.

The implications of this experiment were the limitations in the current calibration techniques and display and tracking technologies were the biggest obstacles preventing AR from being realistic in practical uses.[116] The authors write that the designers seeking to make use of the performance gains of AR systems need to consider how the user manages their attention in such systems and avoid over-reliance on cues from the AR system.[117] The "attention tunneling" could possibly reduce performance in cases where AR cueing overwhelms the user's attention causing distraction from important relevant cues of the physical environment.

In summary, this study was useful in researching and comparing the different forms of instructional media and how they affect the user during an assembly task. The AR in the study works, but in order to make it most effective, the system would need to incorporate additional factors to make it practical for the everyday person. AR would essentially benefit users by overlaying 3D instructions on the actual workpieces which reduced the error rate for the assembly task, decreasing the mental effort in the AR assembly but may cause an over-reliance on cues from the AR system.

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[116] Tang, Arthur, et al. "Comparative Effectiveness of Augmented Reality in Object Assembly." Proceedings of the Conference on Human Factors in Computing Systems - CHI '03, Apr. 2003, doi:10.1145/642611.642626.
[117] Ibid

Chapter 5: Methodologies

5.1 Introduction

In this research it is important to understand how the program applications assist in creating an AR result that can be used for assembly and model making. The applications that are implemented and served to help understand the “Real to Virtual Interpretation” are 1) Rhinoceros3D, 2) Grasshopper3D, 3) Fologram.

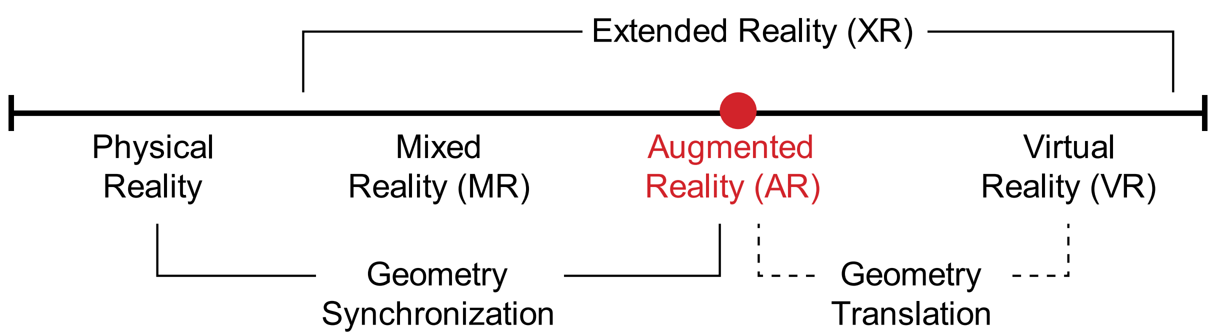

Figure 28. Real to Virtual Interpretation

Source: Author

Rhinoceros3D was originally founded in 1980 by Robert McNeel & Associates. Rhinoceros3D is a computer aided 3D modeling software that serves as the digital space and visualization aspect for the conducted experiments in this research. Rhinoceros3D is chosen as the ideal program due to its compatibility with the visual programming language Grasshopper3D and the mixed reality application Fologram. Grasshopper is a visual programming language and environment that runs within the Rhinoceros 3D computer-aided design (CAD) application. The program was created by David Rutten at Robert McNeel & Associates. Grasshopper is primarily used to build generative algorithms and scripts. Many of Grasshopper's components create 3D geometry. Additional uses of Grasshopper include parametric modelling for structural engineering, parametric modelling for architecture and fabrication, lighting performance analysis for eco-friendly architecture, and building energy consumption. Fologram is a research platform providing a mixed-based reality software for an efficient, faster, and advanced construction process for architecture and design installations. Fologram was founded by Cameron Newnham, Nick van den Berg, and Gwyllim Jahn. Fologram operates on most smart devices and for the Microsoft HoloLens. Fologram accurately positions digital content in 3D space, and automatically corrects for hologram drift over large distances.

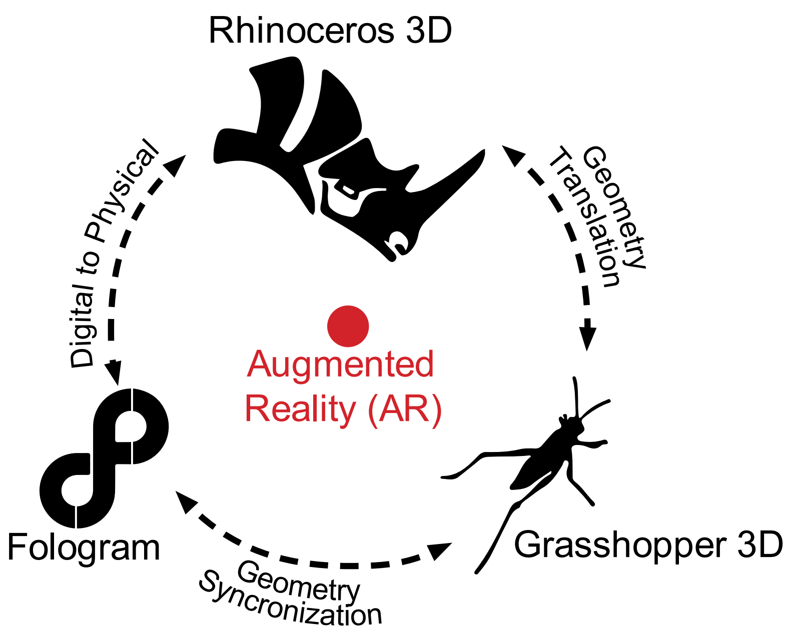

Figure 29. Framework Methodology

Source: Author

By first testing the software with the use of the different hardware (SDAR and HMD), the experimentation then grows to fit the objectives set to learn through building by 1) Creating digital models of traditional Hale, 2) Implement a layering system that can toggle information on and off in AR, 3) List out assembly steps from start to finish in fabrication, and 4) Build a model of a Hale Using the AR Instructions. Through using Smart Device Augmented Reality (SDAR) and Head Mounted Display (HMD) this research puts into focus of how the methodologies are implemented in each experiment.

In setting up the experimentation a digital model needed to be created that represents what the desired "end" result should be. this way the digital model reflected what the physical structure should closely resemble. Each experiment involved two main parts of the grasshopper script. The first part of the script is used to display the wireframe component of the digital structure (figure 30). Used in unison with Fologram, the wireframe of the structure is displayed to the user first indicating the size and scale of the model prior to assembly. The second part of the script involves a "parameter" script that controls the assembly steps (figure 31). This is done through grasshopper where a geometry script and a parameter controller is connected to a "list index" script. The "parameter" script then allows the user to cycle through all the connected geometries in in the "list index". By utilizing the "parameter" script, the model will highlight the portion of the model that notifies the user where an object will be placed before moving to the next step in the assembly procedures.

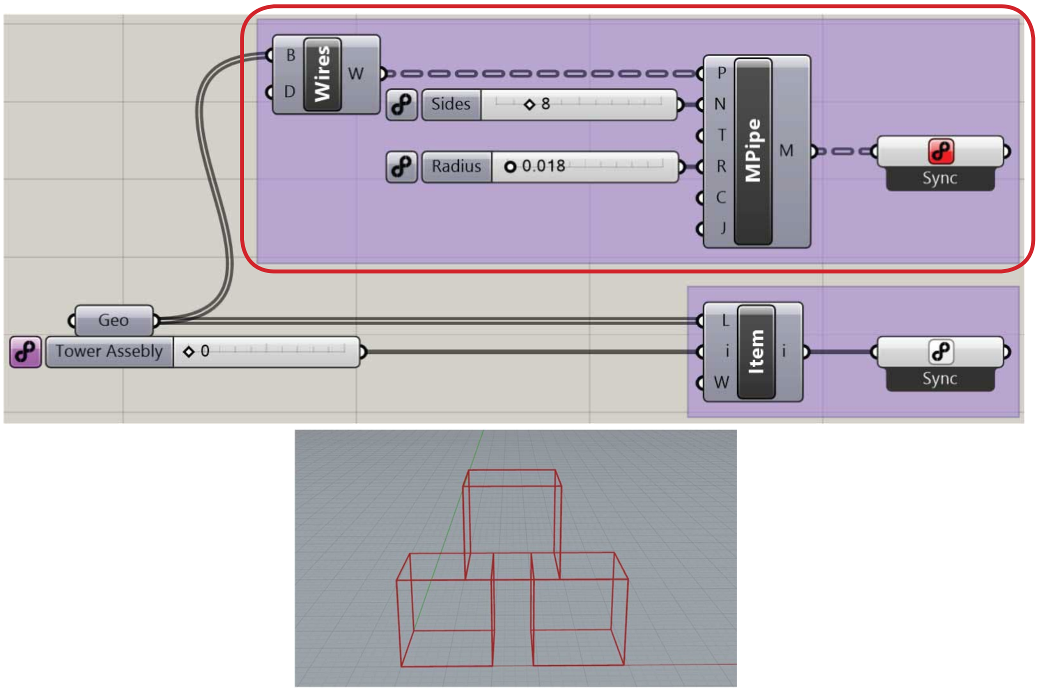

Figure 30. Grasshopper3D Script that Initiates the Assembly Steps

Source: Author

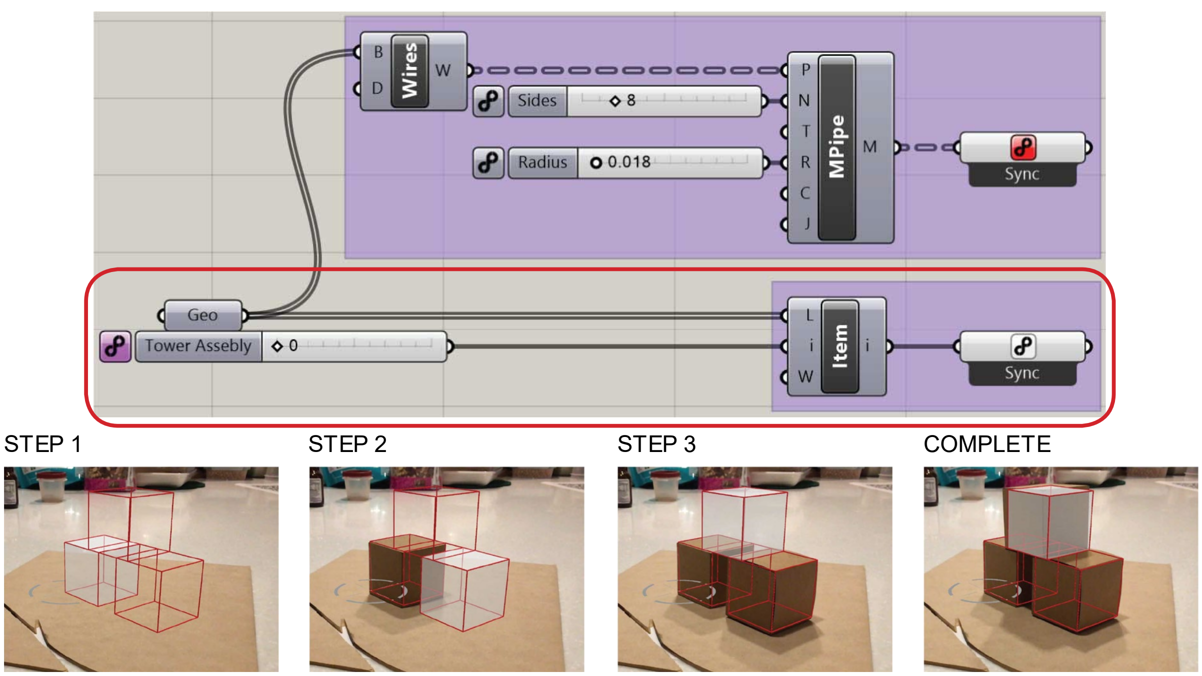

Figure 31. Grasshopper3D Script that Outlines the Digital Model

Source: Author

5.2 Hologram Assembly

The objective of this experiment was to first test out the software by creating a digital model of physical structure, then create the digital instructions needed to create it. This experiment involved stacking three, 2-inch-tall cubes on top of one another to create a tower (figure 32). Due to the experiment involving three blocks, there were only three steps used in the assembly procedures.

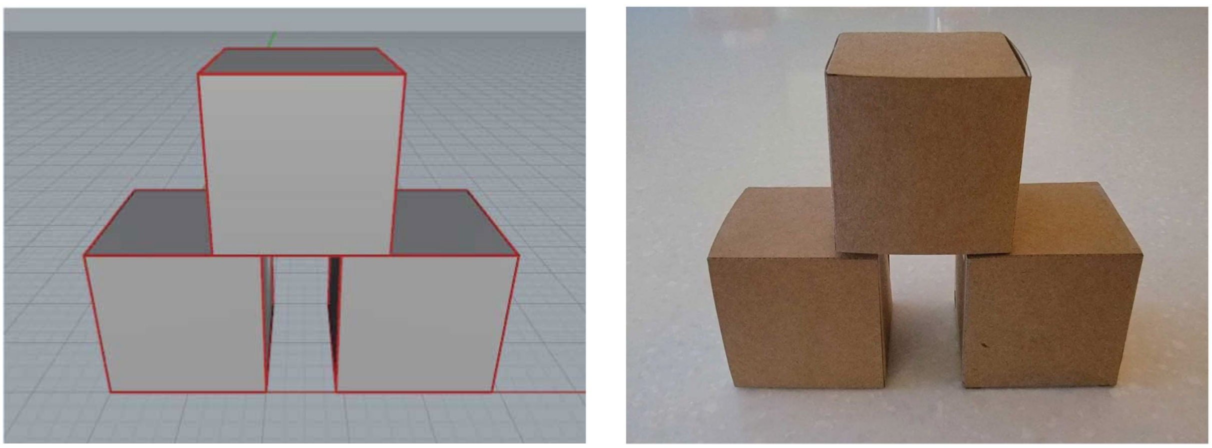

Figure 32. Digital Model (Left) Physical Result (Right)

Source: Author

After doing the initial experiment, additional steps were taken into consideration for the fabrication of the blocks aside from also stacking them on top of one another. The purpose was to test the steps of fabricating the blocks prior to assembling the blocks in a stacked tower. This involved adding a new script that took the shape of the unrolled blocks as 2D geometries of the shapes. Additionally, two new shapes were added to the assembly for more diversity of parts being used, a cube, a pyramid, and a rectangular box (figure 33).

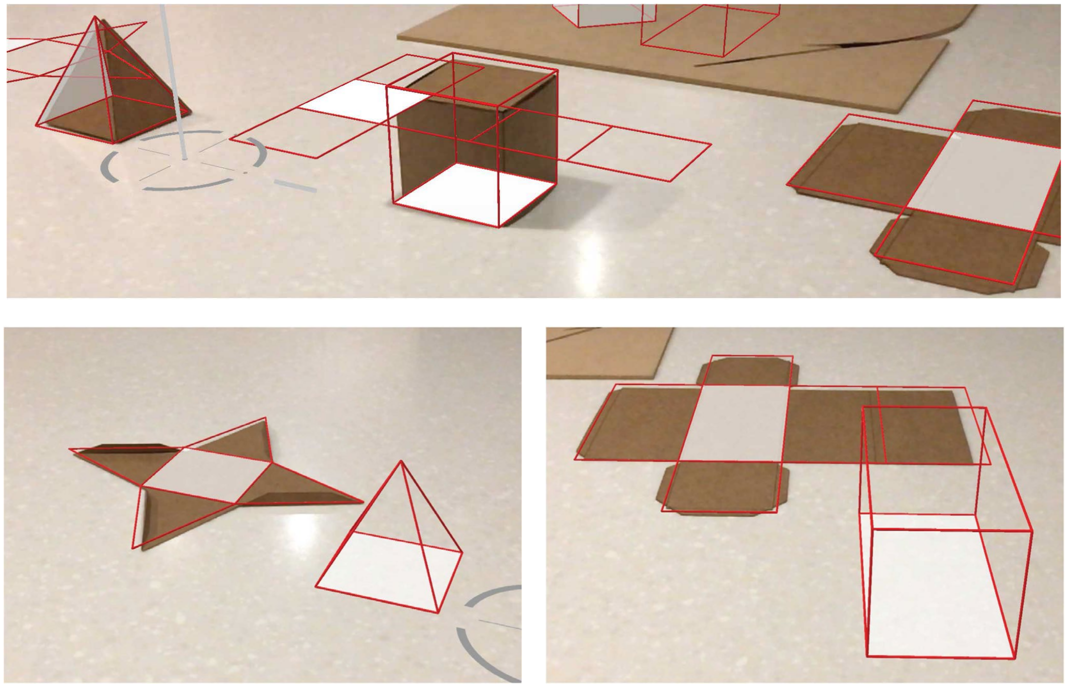

Figure 33. Fabricating New Shapes following AR Assembly Steps

Source: Author

This experiment helped in configuring the grasshopper scripts to be used in a step-by-step procedure, but also helped to show how a smart device like a phone or tablet could utilize Augmented Reality for assembly. From conducting this experiment, the takeaways and opportunities learned were:

1) Understanding the use in applying multiple devices. Due to this experiment making use of a Smart Device Augmented Reality (SDAR), it would have been beneficial to test out the system on different phone operating systems. By testing out the AR result on different devices it would help understand
2) Conducting a thorough opacity test on the AR model. By testing and controlling the opacity of the AR model the viewing experience would then become easier for the user. If the digital model is shown too light in the display, it would make following the

instructions difficult to follow, but if the model is too dark then the user cannot see past the model during assembly. The user should be able to see the overlap of the digital model through SDAR, but at the same time be able to clearly see through the digital overlap on the device to see the physical pieces of the assembly model.

3) Noting the accessibility in using a Smart Device Augmented Reality (SDAR) in assembly. When using a smart device, the user would be limited when interacting with the model for assembly. When using the smart device, the user would be using one hand to hold the device for viewing purposes and the other for interacting with the model, but if the model pieces were heavier or larger in size that would make the usage of a Smart Device Augmented Reality difficult beyond just viewing purposes.

5.3 Furniture Assembly

This experiment uses the ideas and takeaways from the previous hologram assembly and is utilized in a larger scaled model. The assembly for this experiment is to test the scale and size of the object to realistic physics and structure. In addition to the model being made, parts of the digital model needed to account for the sections where pieces of the model made connections, like the location of where screws/nails would be used. This involved adding a new portion to the grasshopper script that highlights the locations of where screws are used and an option to turn off the digital overlay inside the instructions. In understanding the relationship between the digital and physical model, the digital model needed to mimic the various sizes and thicknesses of the materials being used in the assembly. After creating the model, the pieces for physical model can be made.

For this experiment the grasshopper script can be broken down into three separate parts

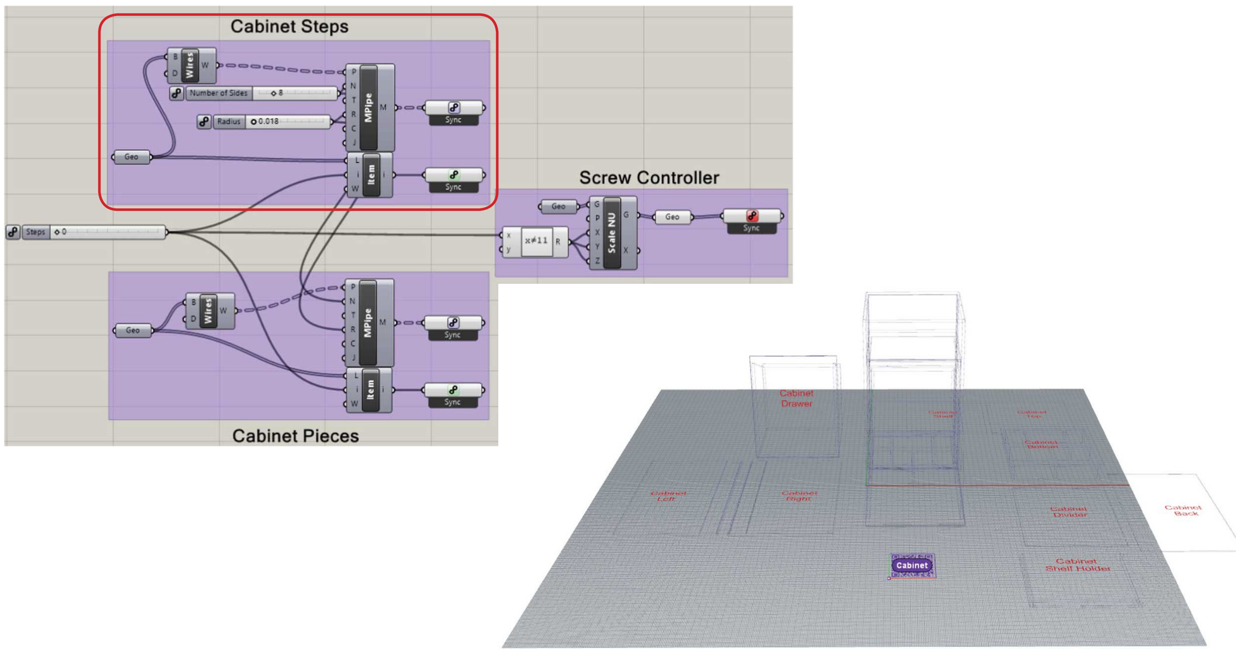

Figure 34. Furniture Assembly: Script for Instructional Steps

Source: Author

1) The instructional steps (figure 34).

   This consists of a "parameter" script that controls the assembly steps through a "list index" script.

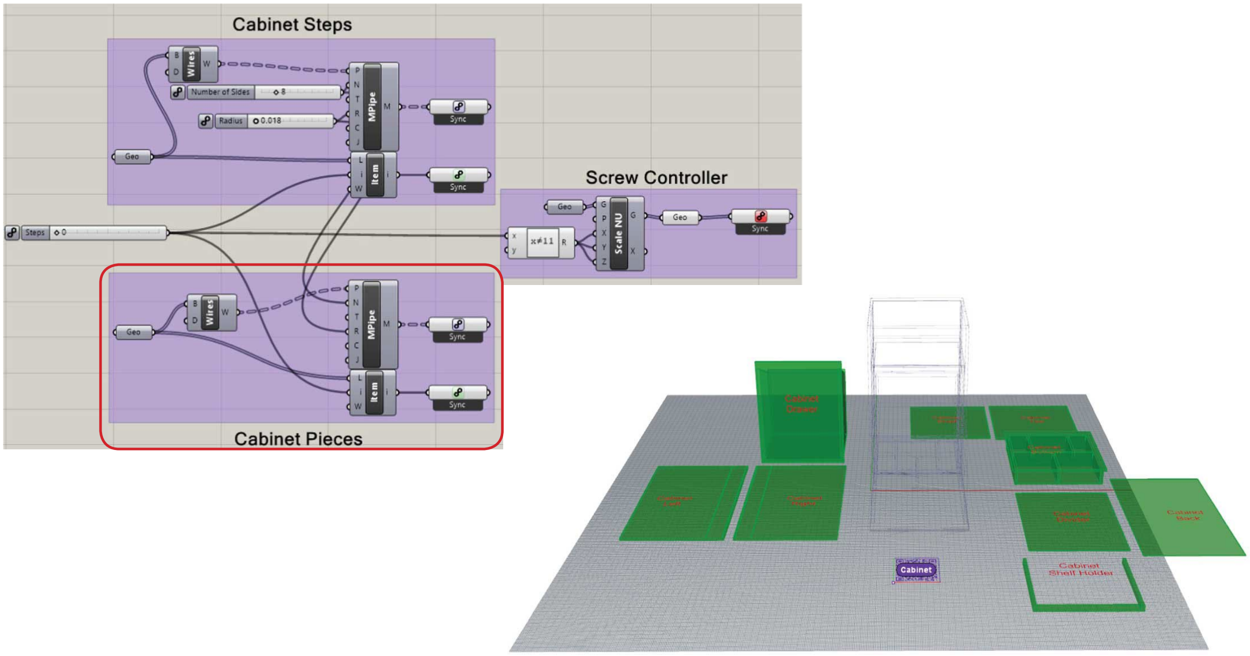

Figure 35. Furniture Assembly: Furniture Pieces

Source: Author

2) Model pieces (figure 35).

A portion of the script that uses the same "parameter" script that controls the assembly steps but highlights the pieces of the model that are involved in each instructional step. Example; step 1, place piece A, at point A. (Piece A, is highlighted so it can be found amongst all other pieces of the model.)

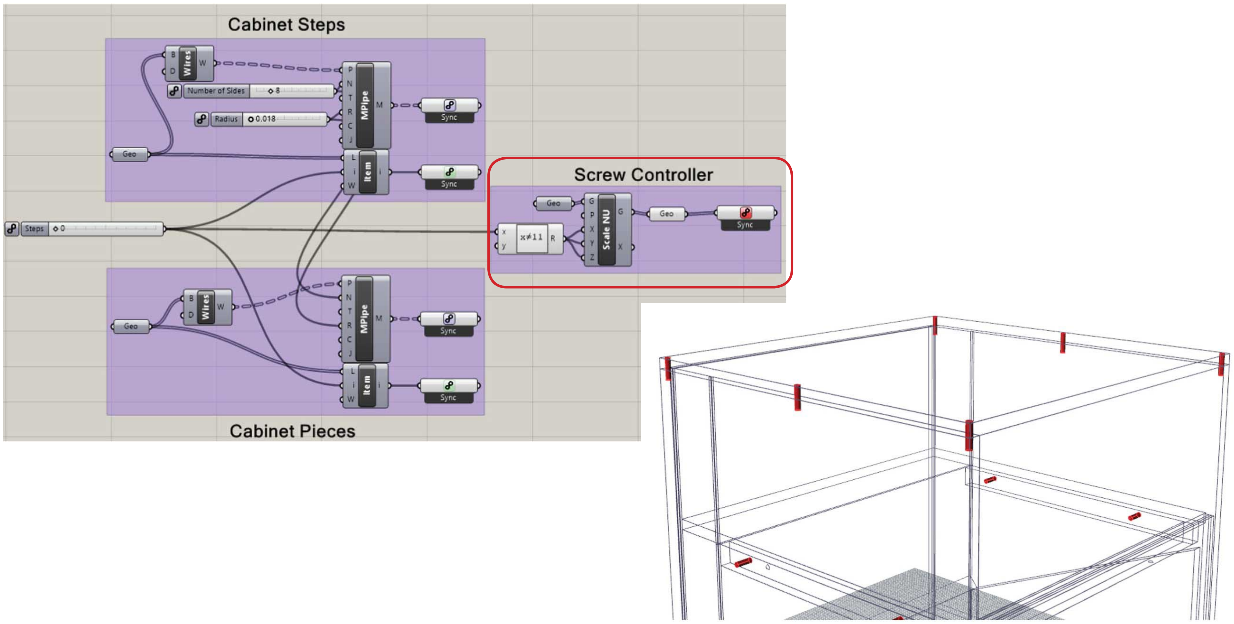

Figure 36. Furniture Assembly: Screw Controller Script

Source: Author

3) The screw controller (figure 36).

Section of the script that highlights the location of where screws are used in the model and additionally can be turned off to help with visibility.

Figure 37. Furniture Assembly (Start) - IPhone (Left,) IPad (Middle), Samsung (Right)

Source: Author

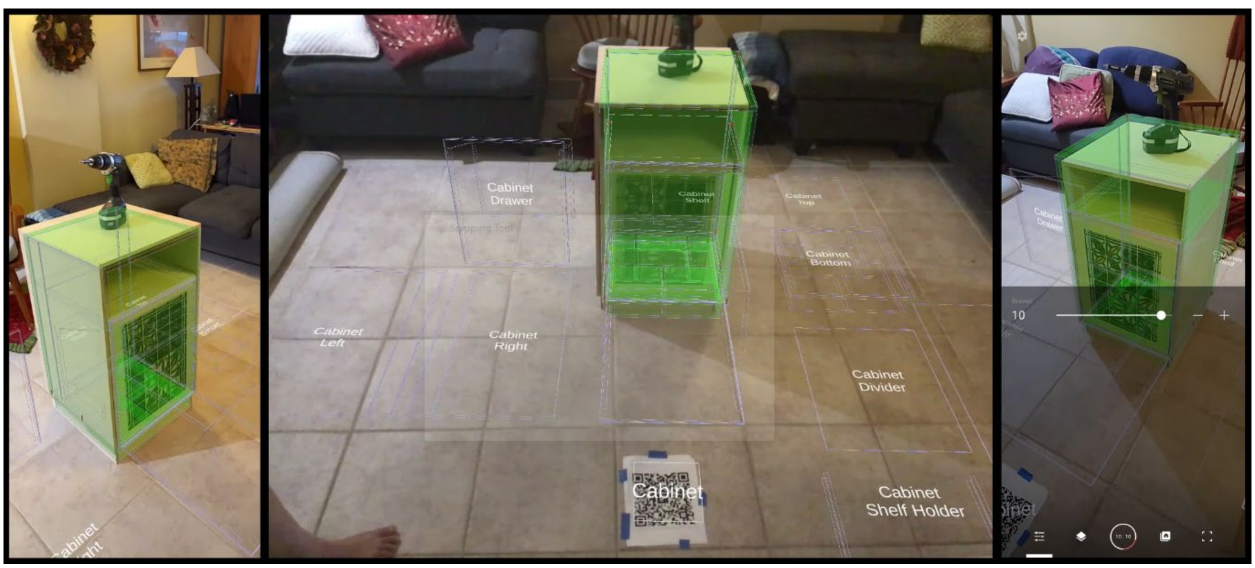

Figure 38. Furniture Assembly (Finished) - IPhone (Left,) IPad (Middle), Samsung (Right)

Source: Author

This experiment helped in understanding how much size and scale can affect the building assembly process. By making a realistic scale model of a piece of furniture, this experiment helps solidify the usefulness and feasibility of using a smart device for more than viewing purposes of an Augmented Reality model. If a user were to buy a furniture item, how could using Augmented Reality help with assembling the furniture item as opposed to paper instructions. From conducting this experiment, the takeaways and opportunities presented were:

1) Usefulness of predrilling holes for the screws in the physical model. By predrilling the holes in the pieces prior to assembly, building the cabinet no longer needed the user to hold a smart device to see the location of where to drill a hole and a screw, the user only needed to drill in the screw. This gives the user a better access to using their hands and less tools required for the assembly.
2) Testing the QR code for the model. A QR code allows the user to anchor the digital model in a physical location and allows the user to freely move about a space so the model does not move. In using a smart device for this assembly more testing on the QR code would have been more beneficial. Though Smart Device Augmented Realty (SDAR) is more accessible compared to a Head Mounted Display (HMD), the drift is higher when the digital model tries to anchor in a specific location. This experiment could have benefited more from using a Head Mounted Display (HMD) or from testing out more QR codes in the assembly procedures.
3) Data saving settings on used devices. This is more specific to recording the assembly rather than just building the model following the assembly steps. If a user were to record their experience in building the model it should be noted that it is important that the device being used can handle being used for long recording times. When recording the AR model, it would benefit the user and the device by pausing or stopping the recording every several minute to keep the device from possible freezing or glitching brought on by the device's operating system.

4) Camera issues of long-term usage. If a smart device is being used for the experiment for longer than 15 minutes, it is possible that the device might start to experience overheating due to extended use of the phone camera and application. If that happens the device may start to experience lag (where the image takes a few seconds to match the location of where the device is pointing) and cause greater drifting with the AR model. This was more noticeable with devices that ran an android operating system, though newer devices tend to do better, IOS devices tended to work for longer periods of time. Best thing to do when a device starts to experience overheating is to pause all actions and let the device cool down.

5.4 Construction assembly

This experiment builds off the previous experiment and focuses on construction assembly of a model using a Head Mounted Display (HMD). This experiment is to test the scale of the model with the addition of working with many different model parts. Learning from the previous experiment, an important factor of using a HMD is that it makes it possible to use more than one hand when following the assembly instructions.

Starting with the digital model, the focus was to make it just the skin and bones of the structure, so the floor, the stud walls, and the framing were the focus. Since each stud wall was different, all the pieces that make up each wall were specific, meaning there were many parts involved in the construction of the model. To help organize the digital model, the model was divided into two parts, one side labeled part A and another side labelled side B (figure 39). Each side contains three stud walls which then get organized by their horizontal and vertical members and given serial numbers to their corresponding wall, for example, Side A, Wall 1-Horizontal member 01 is [AW1-H01].

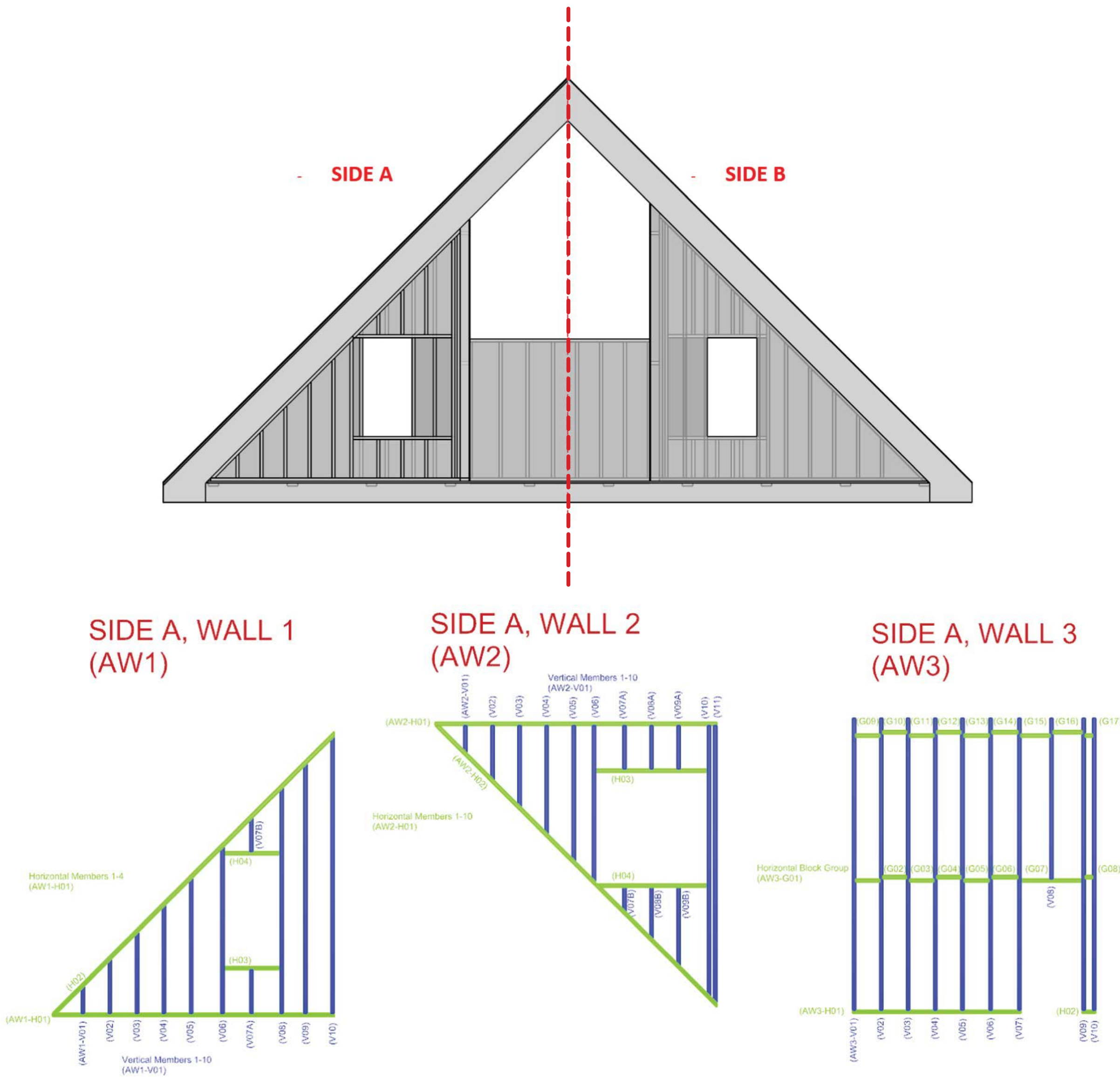

Figure 39. Division of Model, Naming of Vertical and Horizontal Stud Wall Members

Source: Author

These serial numbers are then organized into a chart that separates the pieces into section defined by the side the piece is from, the wall the piece belongs to, and separated into a category based on if the piece is horizontal or vertical (figure 40). The purpose of organizing the pieces into a chart helps with visualizing the number of parts that are needed to make the model in the assembly and if the assembly were a full-size prefabricated house build, this system would be used for organizing the parts similar to the previous experiment with the furniture assembly.

SIDE A			
WALL 1 (AW1)	**WALL 2 (AW2)**	**WALL 3 (AW3)**	
HORIZONTAL PIECES	HORIZONTAL PIECES	HORIZONTAL PIECES	HORIZONTAL BLOCKS
AW1-H01	AW2-H01	AW3-H01	AW3-G01
AW1-H02	AW2-H02	AW3-H02	AW3-G02
AW1-H03	AW2-H03		AW3-G03
AW1-H04	AW2-H04		AW3-G04
			AW3-G05
VERTICAL PIECES	VERTICAL PIECES	VERTICAL PIECES	AW3-G06
AW1-V01	AW2-V01	AW3-V01	AW3-G07
AW1-V02	AW2-V02	AW3-V02	AW3-G08
AW1-V03	AW2-V03	AW3-V03	AW3-G09
AW1-V04	AW2-V04	AW3-V04	AW3-G10
AW1-V05	AW2-V05	AW3-V05	AW3-G11
AW1-V06	AW2-V06	AW3-V06	AW3-G12
AW1-V07A	AW2-V07A	AW3-V07	AW3-G13
AW1-V07B	AW2-V07B	AW3-V08	AW3-G14
AW1-V08	AW2-V08A	AW3-V09	AW3-G15
AW1-V09	AW2-V08B	AW3-V10	AW3-G16
AW1-V10	AW2-V09A		AW3-G17
	AW2-V09B		
	AW2-V10		
	AW2-V11		

Figure 40. Organized Chart of Side A Stud Wall Members

Source: Author

This experiment presses further in the use of the grasshopper script by using multiple “parameter” scripts to operate different steps of the assembly. With the model divided into a number of different parts, the grasshopper script is used to create assembly steps for each wall piece using a similar script for each but changing the contents of what is connected in the geometry collection of each stud wall (figure 41).

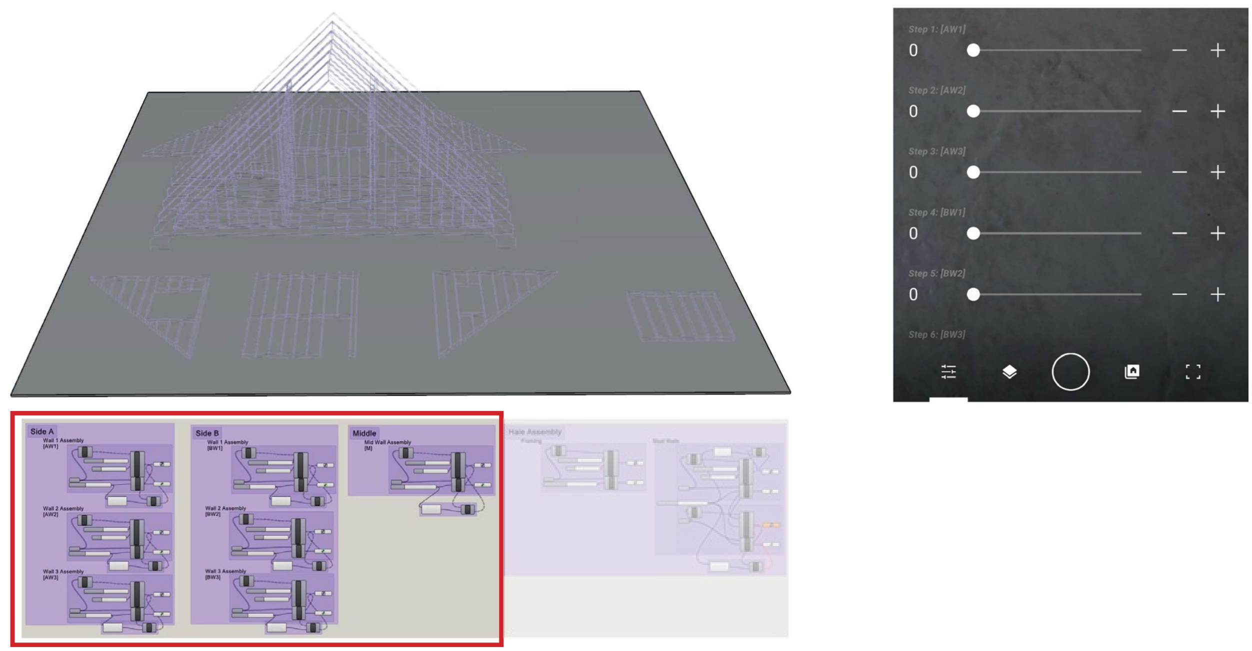

Figure 42. Steps 1-7 (Stud Wall Assembly) of Grasshopper Script Assembly

Source: Author

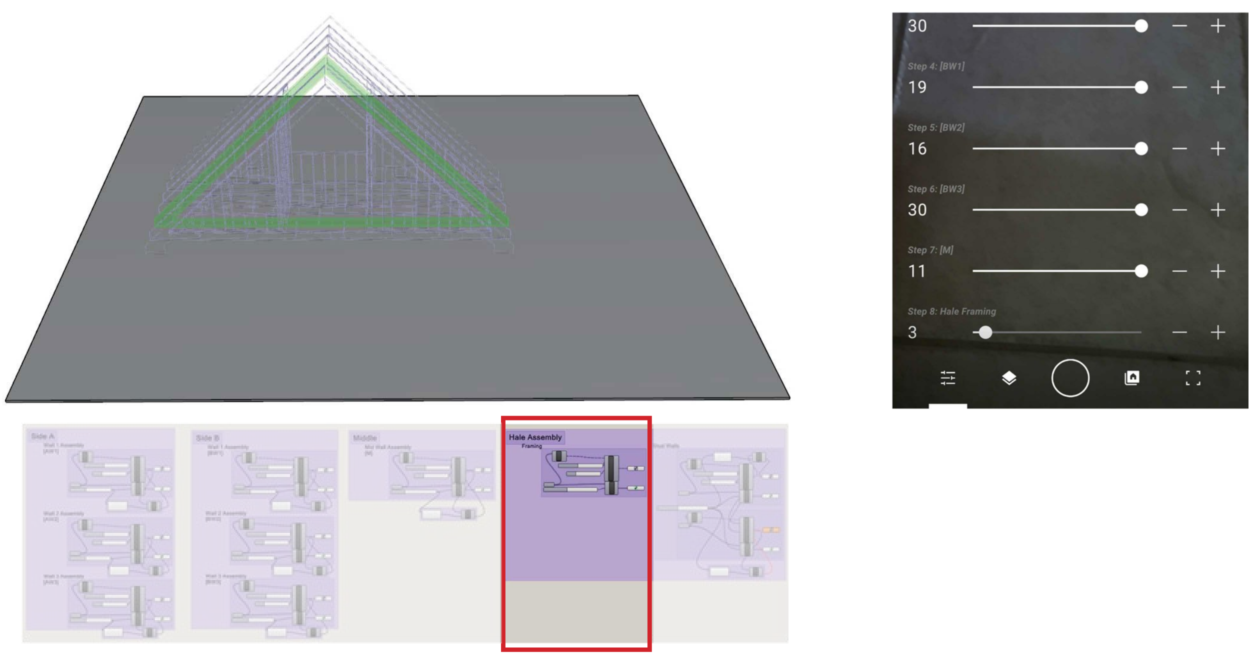

Figure 41. Step 8 (Structural Frame) of Grasshopper Script Assembly

Source: Author

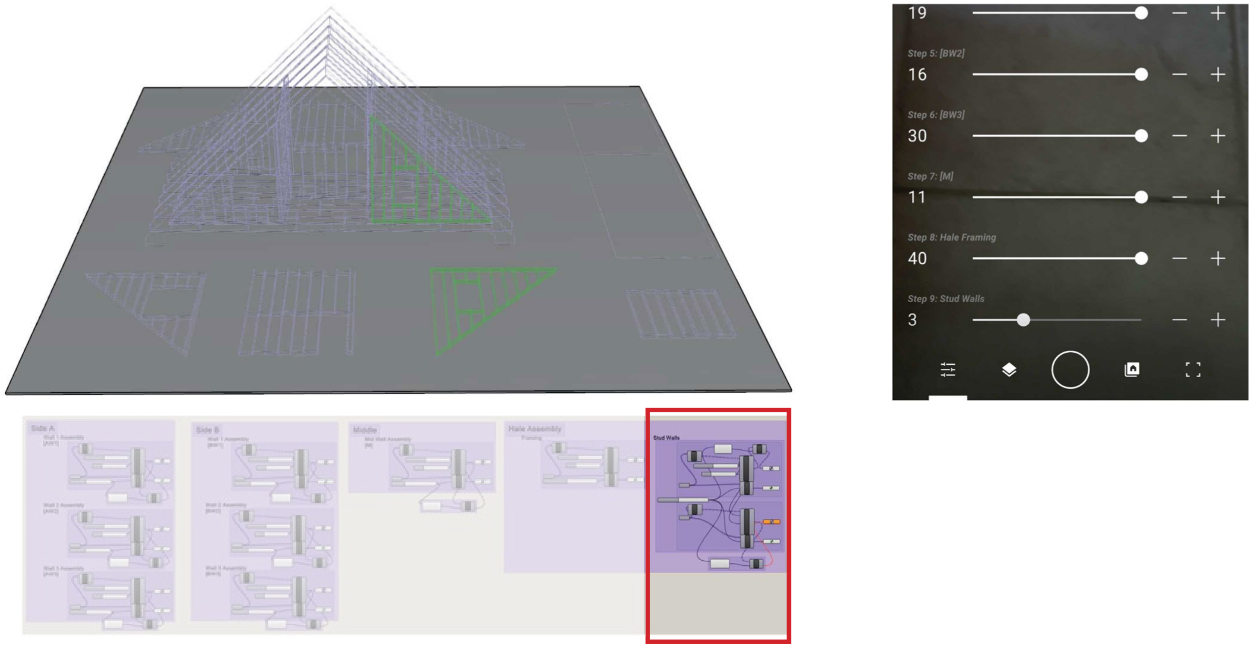

Figure 43. Step 9 (Stud Wall Placement on Structural Frame) of Grasshopper Script Assembly

Source: Author

Steps 1-7 focus on each different stud wall, as step 8 is the assembly of the framing members of the structure, and step 9 is when the stud walls made in the previous steps are then added to the structure to create the overall “bones” of the structure (figure 43).

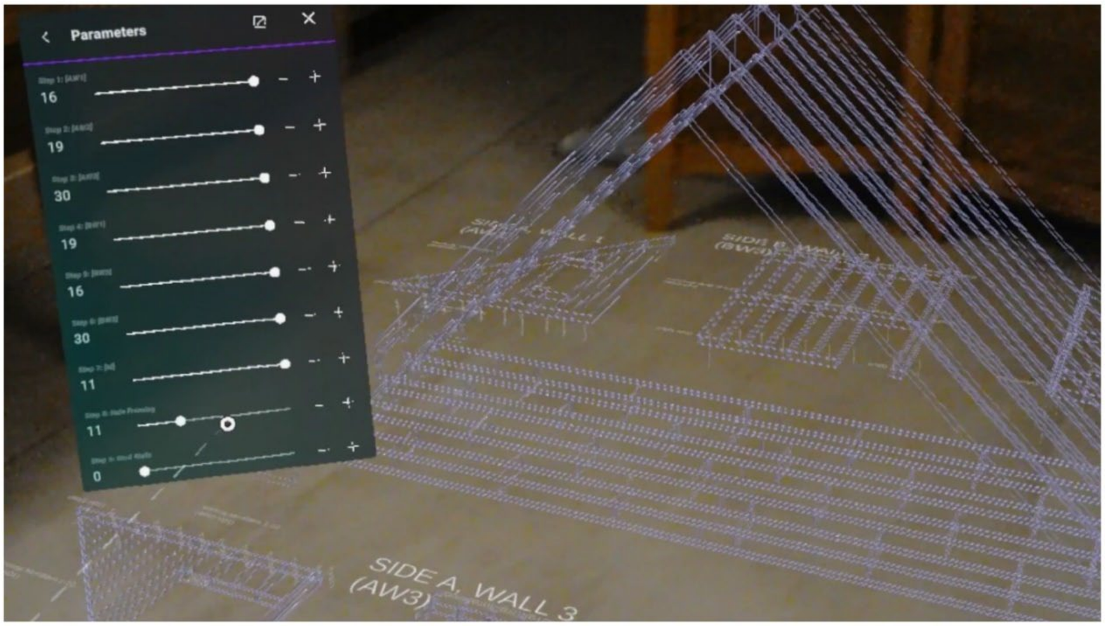

Figure 44. Running AR Assembly of Model Through HoloLens

Source: Author

Though this experiment varied slightly different from the previous two, it was important because testing the digital model of that size with all of the parts of the model helped to figure out if the HMD being used could run a geometry heavy model in real time. In addition to all of the parts being used, the updated grasshopper script made it so each instructional step had more depth to the overall assembly process and gave more attention to each part of the model rather than focusing in the model as a whole. From conducting this experiment, the takeaways and opportunities presented were:

1) Understanding the viewing window created by using the HMD. When using the Microsoft HoloLens to run the experiment, it was important to understand how much the HMD can see compared to how much the user could see. The human eye viewing window is wide due to peripherals, but the HMD will display the AR design as a rectangular window in front of the users' immediate field of vision. This user

interface makes it so when using the HoloLens, it is possible that the entire model might not appear in view of the user and may require the user to take a step back.

2) Setting up a layering system in which the model can display the text from the parts with serial numbers and can be turned off at any time. Similar in the previous experiment with the furniture assembly, this experiment would have benefitted a way to control a toggle switch to turn the text on or off if the text were to get in the way of the model pieces. Though the text could be added to a rhinoceros3D layer, having to swap windows back and forth between the instructions and layers can cause the program to freeze from time to time.
3) Data saving component for using the HMD. In using the Microsoft HoloLens, it is good to keep in mind that there is a 5-minute time setting when it records a video in app. This makes recording a video for an audience difficult if the video were to go past the 5-minute mark. Though the hardware allows the user to immediately record another video after the first one ends, there is a noticeable gap in the recordings if they were stitched together later in post-production.

5.5 Outcomes

Each experiment assisted in refining the grasshopper script and determining which methods work best to run the final application. A Smart device was used to run the first two experiments, although using a smart device appeals to the idea of being more accessible to the casual user, using Smart Device Augmented Reality for some of these experiments pushed the limits of its current use. Using a Smart Device Augmented Reality as opposed to using a Head Mounted Display, is better suited for smaller projects that are best for just viewing purposes rather than instructional assembly. Using a smart device however works great in displaying project scaling by being able to show the size of a project and giving the user an opportunity to walk around the hologram. One thing to keep in mind when using a Smart Device Augmented reality is that each device is different and depending on the device's operating system the view experience can be different.

As opposed to using a Smart Device, a Head Mounted Display gives the user access to using both hands rather than access to using one. This allowed for a easier interaction between the user and the Hologram during the assembly. The HMD operating system runs better for running the holograms and changes in real-time making the workflow almost seamless in start to finish. A downside to a HMD is how it interacts with the user's vision. This meant that the holograms would be visible through the center of the HMD display and would disappear as the user would turn their head, making the hologram of the model disappear in the user's peripherals. Though due to how powerful an operating system can be on a HMD the tracking capabilities are powerful enough to keep the hologram anchored to the placement location even when the hologram is out of the user's field of vision.

Chapter 6: Application of Hale Assembly

According to previous research and experimentation, the best way to approach building a model of a Hale would be though a Head Mounted Display (HMD). Though using a Smart Device Augmented Reality (SDAR) would be more convenient to an average user a smart device would hinder the assembly due to the complexity of the build and limiting the users to only one arm for the build. Additionally, communicating the design through SDAR can be proven difficult if the assembly is being done up close in an interior space.

This Chapter presents the objectives of what the final assembly processes should entail and achieve through building. Clear objectives for the assembly were established through the methodologies where each experiment defined the Grasshopper3d script. The objectives of creating the Hale model through the assembly are:

1) Create digital models of the traditional Hale
2) Implement a layering system to toggle information in the holographic assembly
3) List out steps from start to finish in the fabrication
4) Build a model of Hale using the AR instructions

By following these objectives, the AR assembly should offer an understanding of learning through building.

6.1 Finalizing the Hologram

Part of the design that went into creating the holographic assembly was to create a digital collection of all the different Hale styles and variations. By having each model, the assembly can be broken down into pieces and the Grasshopper3D script can be utilized to create the assembly steps. By utilizing the Fologram add-on “text tag” with the Grasshopper “panel” script, the assembly benefited from having active movable texts that follows the user through the assembly build. The text could be edited in size and location to spot in the model through the Grasshopper script, so regardless of where the user stood the text would always be facing the user. The implications to the text tag were that the text font and color could not be changed in this current version of Fologram. Meaning that if the assembly took place in a less desirable location, reading the text could be difficult to see for the user.

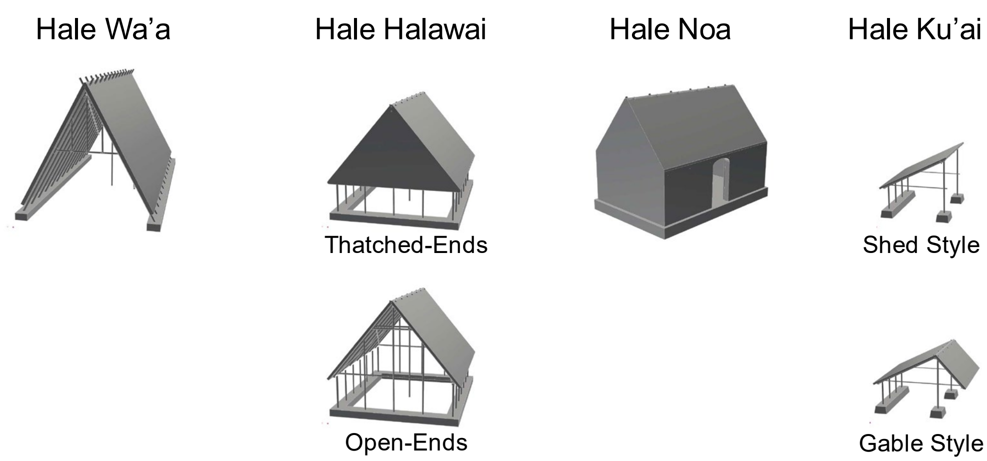

Figure 45. Collection of Hale Models and their Variations for Digital Library

Source: Author

In addition to adding text to the model, diagrams were added to the assembly steps to show the user different methods to tie lashings of different Hale parts. The diagrams had to be saved as .jpg files and added to the Grasshopper script as textures. The textures would then be visible through the hologram model by attaching them to a Fologram "sync object" tag (figure 46).

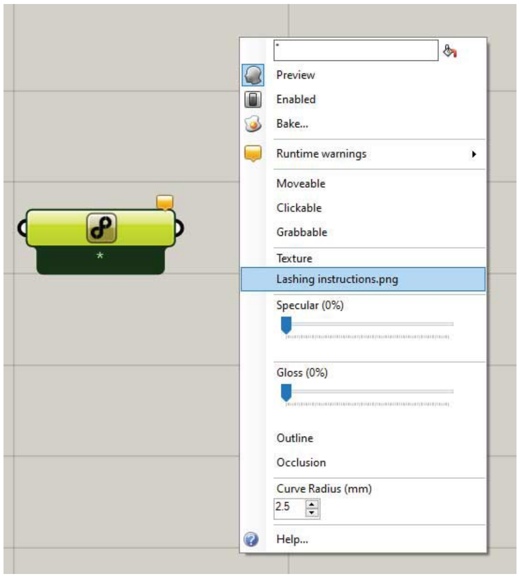

Figure 46. Adding .jpg as a Texture on "Sync Object" Tag

Source: Author

After implementing a system in which the text and diagrams were visible in the model, a Grasshopper script was needed to give the user the option to toggle the text and diagrams off and on if they were to impair the user's view of the assembly process. This layering system formed four toggle commands that controlled the texts and diagrams present in the hologram (figure 47).

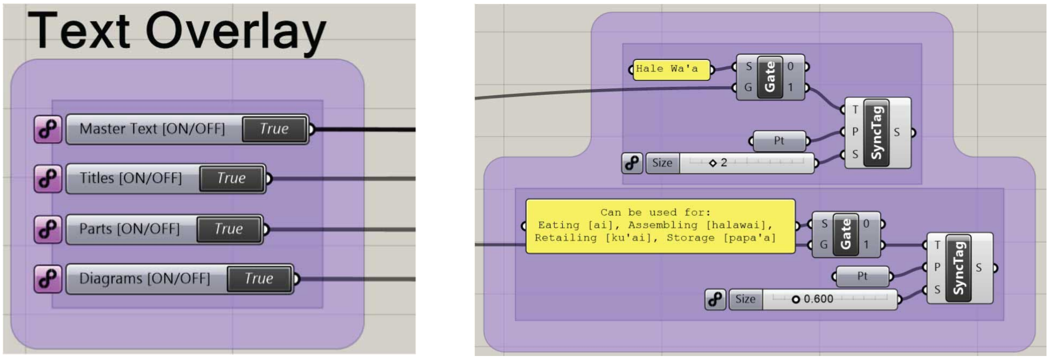

Figure 47. Text Overlay Toggle Switches, Text Tags

Source: Author

From compiling each part of the digital model in Rhinoceros3D and finalizing the Grasshopper3D script with the Fologram tags, the Hale model assembly could proceed through the use of the Microsoft HoloLens.

6.2 Assembly Procedures

The Hale Wa‘a involved 8 steps to the assembly from start to finish. As additional steps to the assembly, sub-steps were added to include visual instructions of the lashing diagrams, the steps are as listed:

1) Foundation

   This step shares the location through AR where the pa pohaku would be built and placed upon (figure 49). This Step is important because if this Hale were built at a full scale, the hologram would show the location of pa pohaku and how deep to dig into the earth for its placement. Pa Pohaku is a collection of local stones that are used to build up the foundation wall for a Hale.

Figure 49. Assessing the QR Code Prior to Assembly

Source: Author

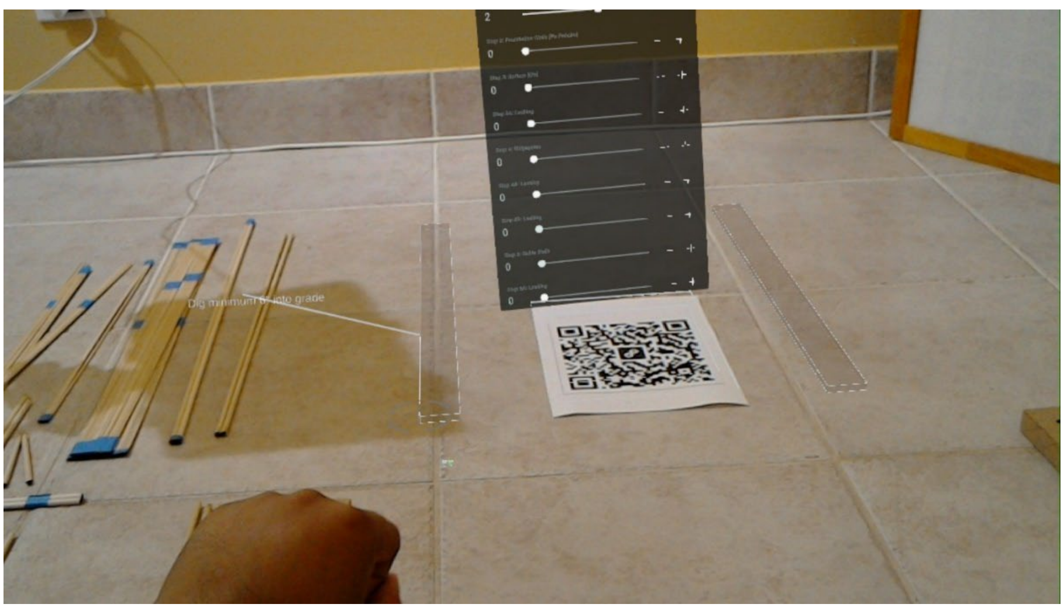

Figure 48. AR Assembly Highlighting Foundation for Pa Pohaku

Source: Author

2) Pa Pohaku (Foundation Walls)

The pa pohaku is placed where the hologram is shown "green" as an indication of object placement. The completion of this step leaves the outline of the digital pa pohaku overlaying on the Pa Pohaku that was placed (figure 50).

Figure 50. Placement of Pa Pohaku

Source: Author

3) Oʻa (Rafters)

3A) Lashing Instructions

The procedures will then show through the hologram where the oʻa will be placed in the pa pohaku (figure 51). Each oʻa is highlighted in the assembly steps, one by one, additionally giving the user visual instructions on how to tie the lashing around each oʻa (figure 52).

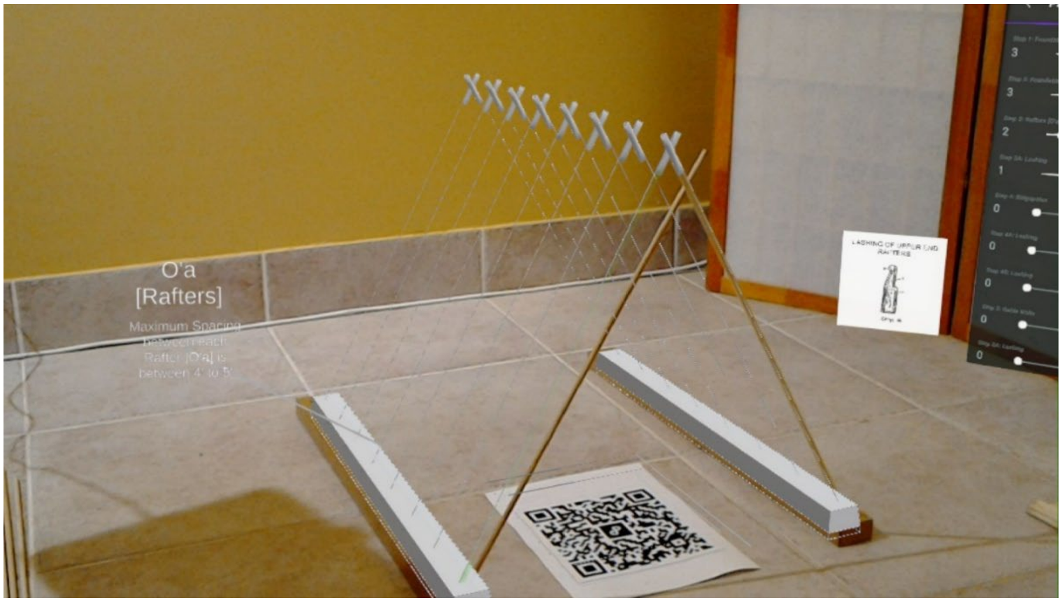

Figure 51. Placement of Oʻa Highlighted by Hologram

Source: Author

Figure 52. User Following Diagram of Lashing Instructions for O'a

Source: Author

4) Ridge Poles

4A-B) Lashing Instructions

In the assembly, a pou hana (ridge post) is erected under the kauhuhu (ridge pole) then lashed together (figure 54). Following the lashing of the ridge post to the ridge pole, the kuaʻiole (upper ridge pole) is then placed on top between the oʻa and lashed together with the kauhuhu. The lashing of the two ridgepoles are then diagramed and displayed for the user to see and follow (figure 53).

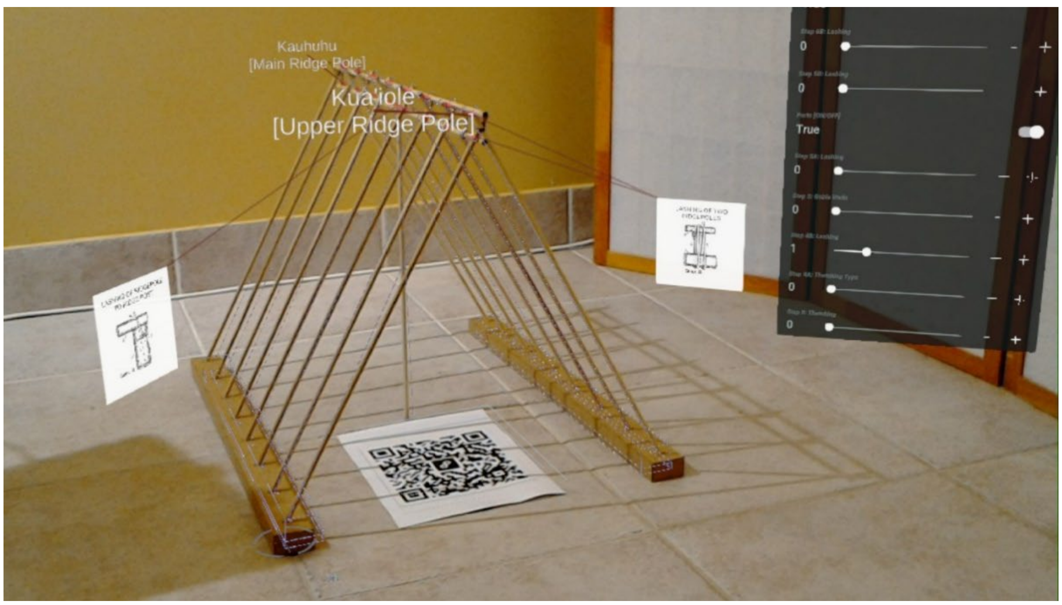

Figure 53. Lashing Instructions of Pou Hana (Ridge Post) and both Ridge Poles (Kauhuhu & Kuaʻiole)

Source: Author

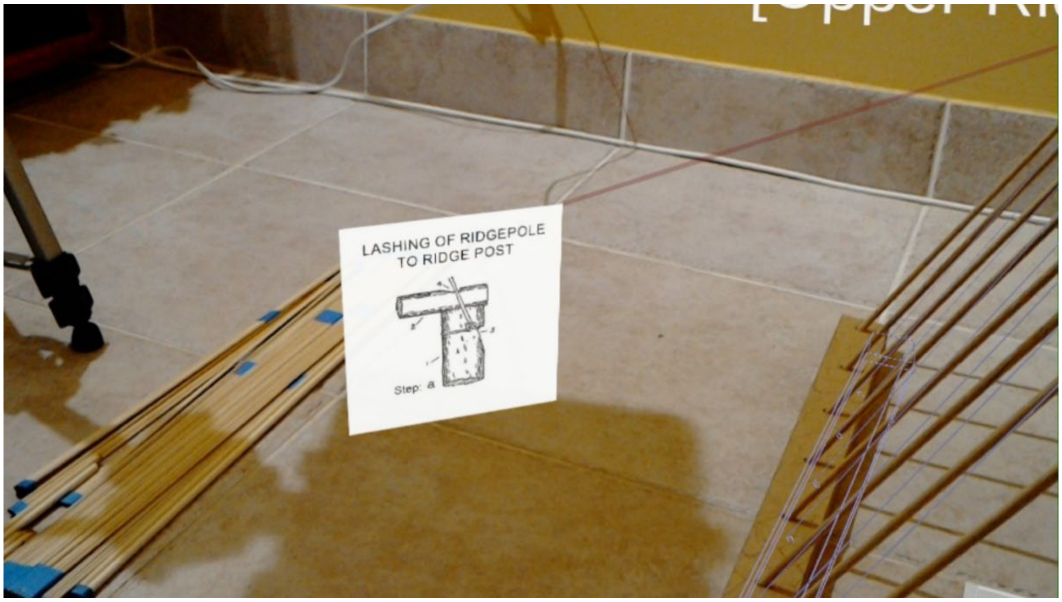

Figure 54. Lashing Instructions of Pou Hana (Ridge Post) to Kauhuhu (Ridge Pole)

Source: Author

5) Gable Walls

5A-F) Lashing Instructions

The gable is built on both ends of the Hale attached to the oʻa and kauhuhu on the ends of the model (figure 55). Each gable wall is comprised of a kalapau (gable end tie), two kukuna liʻi (upper wall post), and a kupono (gable ridge pole). After the kalapau and kupono are lashed on to the model, the kukuna liʻi gets lashed to the kalapau and the oʻa (figure 56).

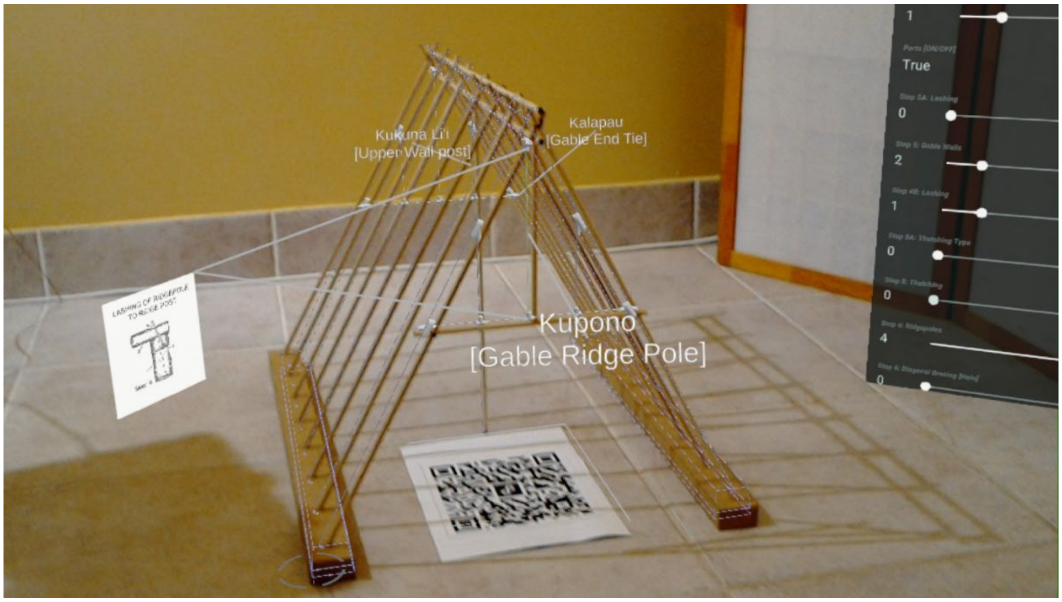

Figure 56. Gable End of The Hale Wa'a with Lashing Diagrams

Source: Author

Figure 55. Kukuna Li'i (Upper Wall Post) Lashing Connection to O'a (Rafter) and Kalapau (Gable End Tie)

Source: Author

6) Holo (Diagonal Bracing)

6A-B) Lashing Instructions

The holo are the diagonal braces that are lashed to the oʻa starting from one end up near the kauhuhu down to the pa pohaku (figure 57). The holo helps to keep the structure sturdy and keeps the oʻa from shifting over time.

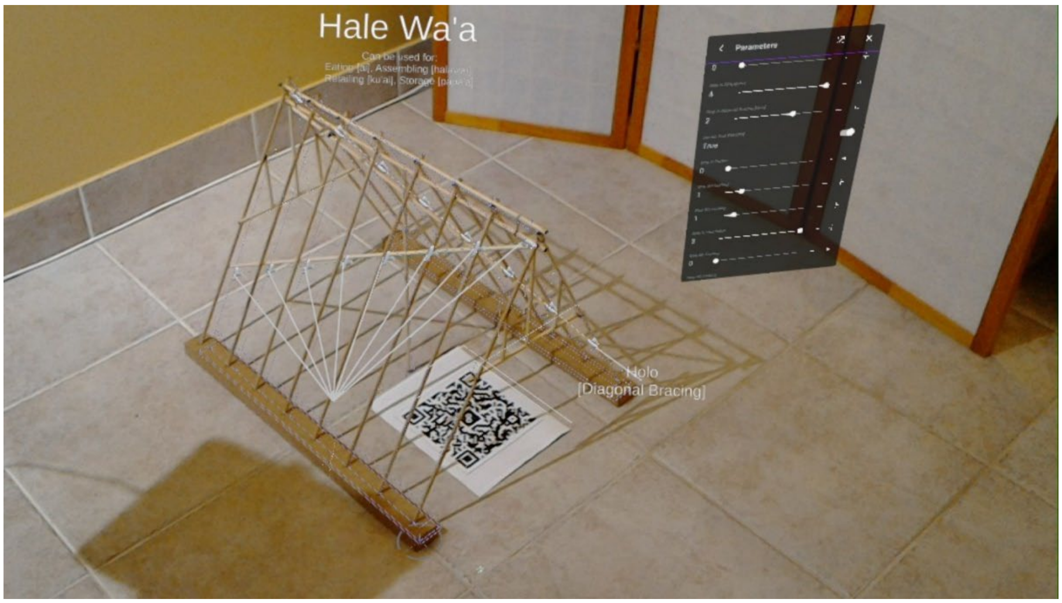

Figure 57. Holo (Diagonal Bracing) Placement in the AR Assembly process

Source: Author

7) ʻAho Pueo (Purlins)

7A-B) Lashing

Purlins are used to attach thatching on to the Hale. Purlins span horizontally across the oʻa (figure 58), then lashed vertically lined up with the oʻa with the horizontal purlins in between (figure 60). This spacing additionally benefits the Hale by keeping the thatching from making direct contact with the oʻa (figure 59). If the thatching takes in water, the smaller and replaceable purlins can deteriorate rather than the oʻa which holds up the Hale. Purlins cover the exterior of the Hale underneath the thatching (figure 61).

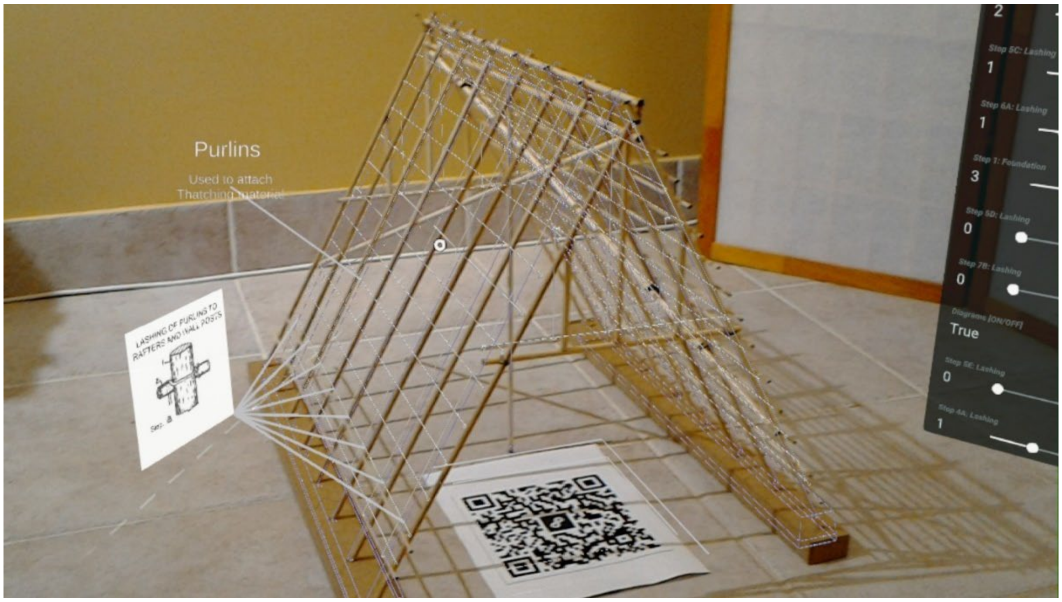

Figure 59. Assembly Placement of Horizontal Purlins Against O'a

Source: Author

Figure 58. Placement of Vertical Purlins Over the Horizontal Purlins

Source: Author

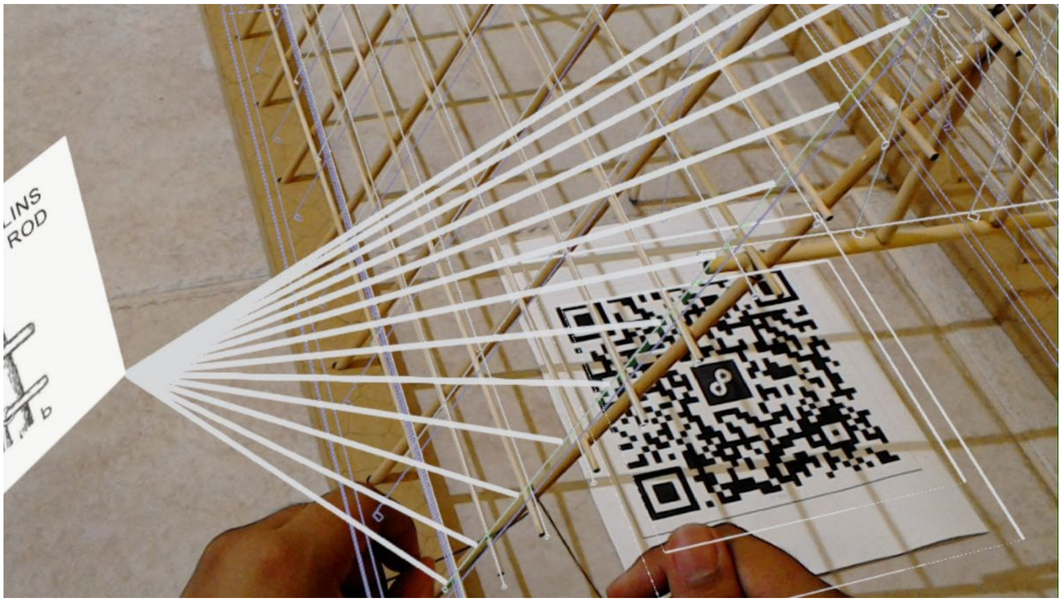

Figure 60. User Lashing Vertical Purlins to Horizontal Purlins and O'a Following Lashing Diagram

Source: Author

8) Ako (Thatching)

8A) Thatching Type

During the AR assembly, the user is given different thatching options to follow depending on the thatching materials (figure 61). The user can then find the material that they have and can follow the diagram on how to lash the thatching to the purlins (figure 62). The upper thatching is joined by overlapping with the purlin above it (figure 63). The Thatching is then attached to the purlins on the side of the Hale. Depending on the specific thatching material there are a few different ways the thatching can be attached to the Hale (figure 64). Thatching could be made with pili grass bundle, pandanus leaves, ti leaves, and more depending on the resources of the location where the Hale is being built. Of the various thatch materials, the Hawaiians preferred pili grass because of its color and its fragrance when freshly cut.

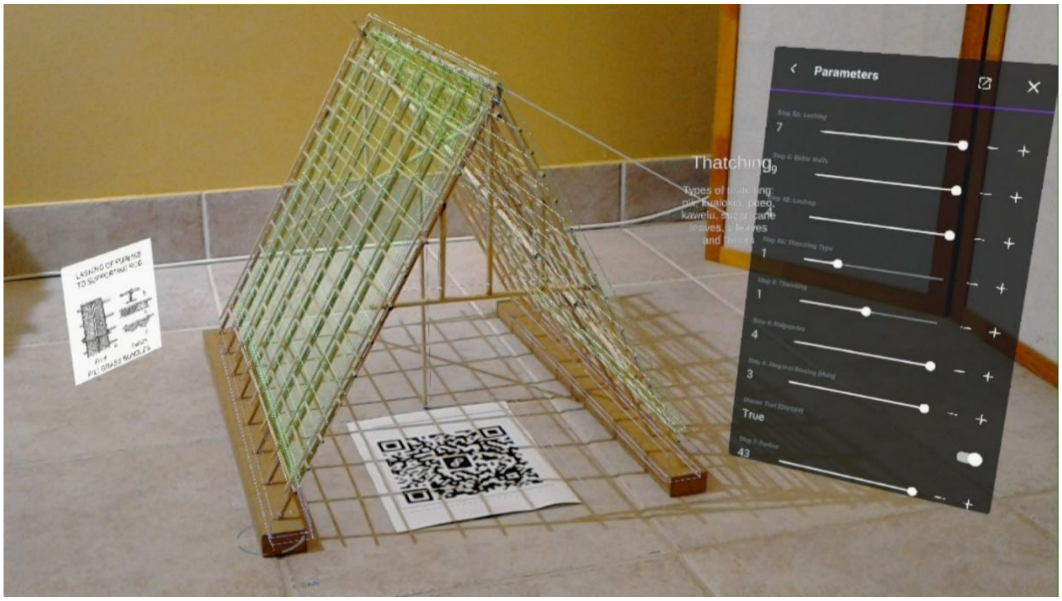

Figure 62. User Assessing the Variety of Thatching Options of the Hale

Source: Author

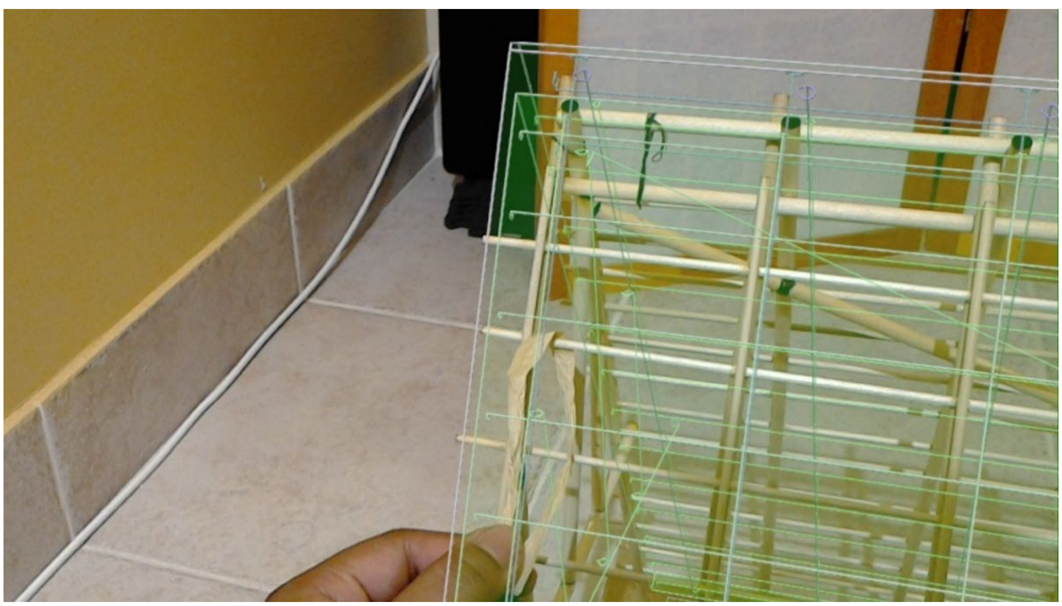

Figure 61. User Following the Pandanus Thatching Technique

Source: Author

Figure 64. The Layering of the Thatching on the Purlins Following Thatching Diagram

Source: Author

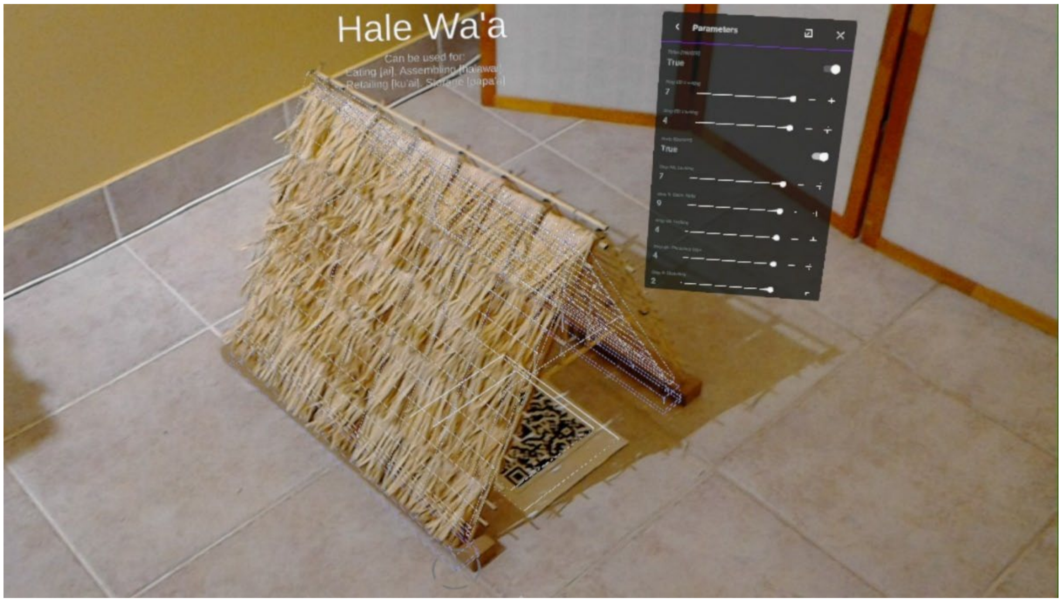

Figure 63. Thatching of the Hale Wa'a Mimicking the Pandanus Thatching Technique

Source: Author

Chapter 7: Conclusion

The Hawaiian Hale has been around for hundreds of years, but in present day Hawaiʻi these structures are mere historic buildings that can be found in museums and cultural sites. The indigenous people of Hawaiʻi must be appreciated and looked to in the future and not merely as a society stuck in history. By understanding the history of Hawaiian architecture such as construction methods, materials used, design elements this project showcased the importance of the Hale and allowed for a deeper dive into the past before showcasing new technological advancements that can be used in the future.

Native Hawaiian cultural practitioners are valued in Hawaiʻi as the original stewards of the Hawaiian Islands and for the wisdom that they hold. If Hawaiian culture is to be appreciated and valued today then every industry, including architects must learn from their lineage and knowledge. In addition, Hawaiian culture is not stagnant and is continually growing. Architectural tools and knowledge can also be shared and incorporated in the growth.

Hawaiian culture through continued cultural practices, education, and preservation continues to thrive now and will continue to thrive in the future. This research discusses the importance of utilizing tools such as augmented reality and mixed realities to future the preservation of Hawaiian culture. By allowing more people to access the knowledge of the Hale and even construct one. Having a holographic assembly of the Hale allows for accessibility to Hawaiian culture and can enable further education and a deeper understanding to Native Hawaiians and locals alike. The purpose of this Research was to showcase the potential use and success of holographic assembly as a hands-on education tool that can also be used in construction.

This section will recap previous topics and the application assembly build. Additionally, this chapter will discuss the success, limitations, and improvements that can be made with regards to holographic assembly of not only a traditional Hawaiian Hale but other fabrications, design, and construction as well.

7.1 Achievements

In the assembly of the Hale model, real-time feedback was achieved through the procedural steps in the model-making process. Like the transitions made from placing the ridge poles to the rafters.

In addition, creating each Hale style contributed to forming a viewing library where the user can cycle through each holographic model prior to building it. By making use of the AR assembly, the user is given the opportunity to learn hands-on. The model-making process is made easier by overlaying the hologram on the model and the user is given text cues in addition to following more complicated steps like tying the lashings of the Hale. Providing this system promotes the purposes of being able to teach traditional Hawaiian building methods along with sharing the cultural significance of building a traditional Hale.

7.2 Limitations

Through experimentation and research conducted on this topic, there were a few implications that came with doing this study. Although there were hands-on experiments done to create the methodologies of the final assembly of the Hale model, none of those experiments were nearly as long and as intense in the final assembly. Through wearing the HoloLens for an extensive amount of time, visual fatigue was inflicted on the user which made wearing the device longer than three hours difficult. To offset the fatigue, it was useful to pause the assembly process to charge the device before continuing further because if the HoloLens stayed in use for the entire assembly without break, the battery would not have lasted.

Additionally, the HoloLens created a viewing experience that was different for the user that varied from what an audience would see from a recording of the assembly build. Due to the see-through display of the HMD, the user has full access to their peripheral vision, but the Hologram models would only be visible through a borderless window centered at the middle of the HoloLens display screen. This also meant that anything being recorded through the HoloLens would be the size of that borderless window and anything the user can see beyond that would not be seen or captured on video. For assembly and building purposes this worked out fine, but if the assembly was recorded to be shown to an audience, the audience could feel a sense of disorientation from the head movements of the user.

The viewing experience also differed slightly in the opacity of the hologram the user would see compared to what the audience would see. The user would see a defined outline of the model that was transparent enough to see through, but an audience would have a hard time seeing the outlines of the model. If the user wanted to record the assembly process for the audience to see how the user would see, the user would need to increase the opacity of the hologram to the level in which the user might have a difficult time seeing the model beneath the hologram.

Using an HMD for the assembly process over a smart device was better for freeing up the user's hands for the assembly, but if this experiment relied solely on using Smart Device Augmented Reality (SDAR) the assembly would need more than one person to utilize. A smart device would benefit more from this experiment if it were used strictly for view purposes and not for assembly.

7.3 Future Uses

The uses of this kind of holographic assembly allows for wider audience to participation. Ideally, if a HoloLens was implemented it would be nice if an update could be utilized that allowed the ability to reduce the sun exposure. If this update took place, then the application for holographic assembly could be used in outdoor settings.

In addition, Fologram is always creating more updates on its application. This would give users the ability to have more customization options with the "text tag" that can be used in Grasshopper3D. Furthermore, this would allow for the opportunity to create a more friendly User Interface (UI) with the user. Additionally, making it possible to add videos or add moving ".gif" images in place of ".jpg" images in the assembly process would make the tying of the lashings easier for the user.

Ultimately, the holographic assembly shares how users can build and learn about the traditional Hawaiian Hale through a hands-on experience. This system and application would have an increased benefit if it was used in a cultural center that focused on sharing Hawaiian culture and knowledge with the community. If cultural centers had an HMD or used QR markers for smart devices for guests to use, these individuals would have a very hands-on learning experience from viewing the hologram. This hands-on learning experience would hopefully foster a deeper appreciation and understanding of Native Hawaiian culture and allow for further conservation of this indigenous knowledge.

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