Augmented Woodworking

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Abstract

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This thesis explores the use of a head mounted, line-of-sight Augmented Reality device which supports woodworking tasks in the fabrication process of furniture, such as preparing a layout of parts on a sheet of plywood, generating a cutting list, setting-up a table saw for precise cuts, and previewing the furniture.

The design of a new line of sight application for woodworking is based on observations in the woodshop, try-outs in the form of applying woodworking techniques in the fabrication of a cabinet, and work with expert craftsmen in the shop. Insights into woodworking were combined with a review of the emerging technologies of head-mounted Augmented Reality devices to investigate design requirements for the integration of an AR system into the woodworking setting. The resulting design is presented as a video prototype that illustrates new types of line-of-sight visual support for woodworking.

Augmented Woodworking

Derek Burkhardsmeier

Master of Design Thesis Documentation

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Background

Introduction

Technology empowers individuals to perform at high standards. It helps humans to access resources at their fingertips, see information in context, work at great precision, and become highly efficient in their daily tasks. Today, more than ever, technology is expanding rapidly from desktop computing, to mobile phones and wearable devices. With Augmented Reality (AR), the digital and physical world can finally blend together, allowing humans to see contextualized information hands-free in their field of view, embedded in their natural surroundings.

Over the course of the past year, I have explored Augmented Reality's potential through the lens of a woodworker. By bridging technology and craft I endeavored to understand the importance of context when designing augmented experiences. This thesis reflects my research of Augmented Reality, discussions with master woodworkers, research through design, and the dissection of my augmented experience. As a designer, it is truly an exciting time to push the boundaries of technology by exploring our opportunities to assist and increase a woodworker's performance.

What is Augmented Reality?

In the last 5 years, Augmented Reality (AR) has emerged as an increasingly popular technology allowing users to see virtual images in their real environments (Azuma e al., 2001). In 1995, Milgram et al. established the Reality-Virtuality Continuum (Fig 1). On one end of the continuum is human's reality – seeing real physical objects – on the opposite, a completely fabricated reality – seeing an entirely new world through a headset – between the two ends is mixed reality or AR. This intersection is where the digital and physical blend together. Currently, various technology companies are interested in this new computational tool. Malcom McCullough sees computational tools as an 'extending tool' that allow forms and ideas to be materialized in new and concrete ways (McCullough, 1998). AR is considered an extending tool because it provides an extension to the human vision.

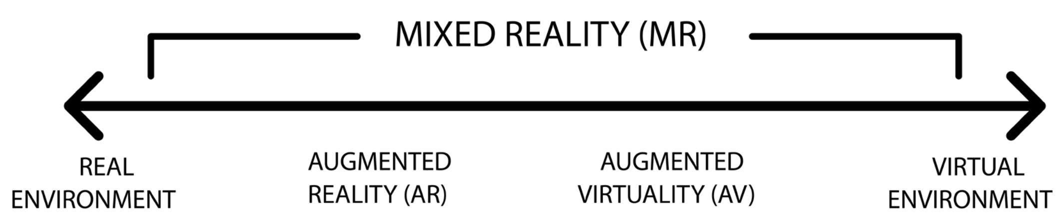


Fig 1. Reality-Virtuality Continuum

History of Augmented Reality

Although AR can appear as a new phenomenon it was first introduced in World War II when the British developed the Mark VIII Airborne Interception Radar Gunsighting's windscreen project. This system superimposed a radar screen directly on the pilots windshield (Vaughan-Nichols 2009). In 1968, Ivan Sutherland and Bob Sproull created the first head mounted display system (Fig 2).

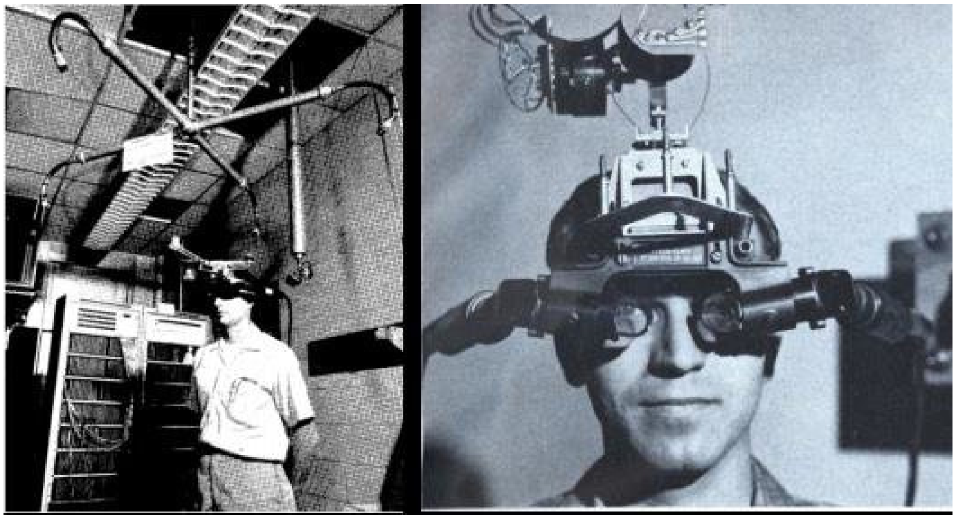


Fig 2. The Sourd of Damocles. (1968)

Their device, nicknamed “the Sword of Damocles”, was a primitive machine in terms of user interface and realism but was able to track a person’s gaze (Sutherland 1968). By tracking a person’s gaze, they were able to position the viewer’s perspective correctly within a wireframe box. This discovery is the foundation of all modern head-mounted displays (HMD). By the 1990s, Tom Caudell, coined the word ‘Augmented Reality’ when he was working for Boeing and designed a head-mounted digital display that would help workers wire aircrafts by superimposing schematics on the factory floor (Vaughan-Nichols 2009). As technology becomes smaller and more efficient, its use has shifted from the military and engineering fields to consumer electronics. The most common form of Augmented Reality is currently found in mobile phones.

Mobile AR

Mobile phones are more powerful than ever. With the widespread adoption of smart phones and their strong specifications like full color displays, integrated cameras, and fast processors; developers are giving Augmented Reality to everyone. Individuals can capture Pokémon with Pokémon Go, manipulate their faces with SnapChat, or insert virtual furniture into their room with IKEA Place (Fig 3). Each of these applications provide a fun user experience but are not necessarily practical when it comes to productivity.

The difficulty with Mobile AR is that it is not a true augmented

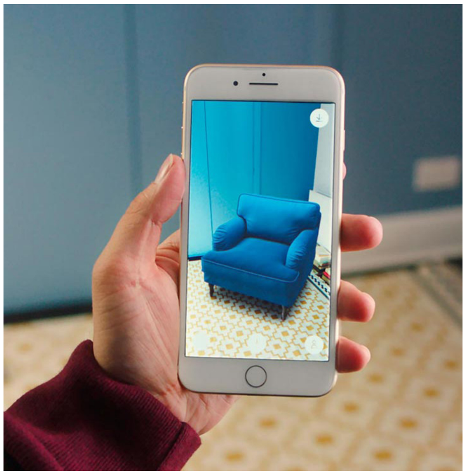


Fig 3. IKEA Place

reality experience, it is an illusion. The mobile phone is a middleware between the user and the real world. Users look at their phone and see a picture of their environment with a piece of furniture appearing as if it is part of that environment. That piece of furniture is only a representation of a 3D object locked onto a 2D screen. The user cannot reach out to touch the object.

However, head-mounted displays provide users with a true augmented experience, allowing the user to view holograms directly in their field of view and enabling them to reach out as if to touch the hologram.

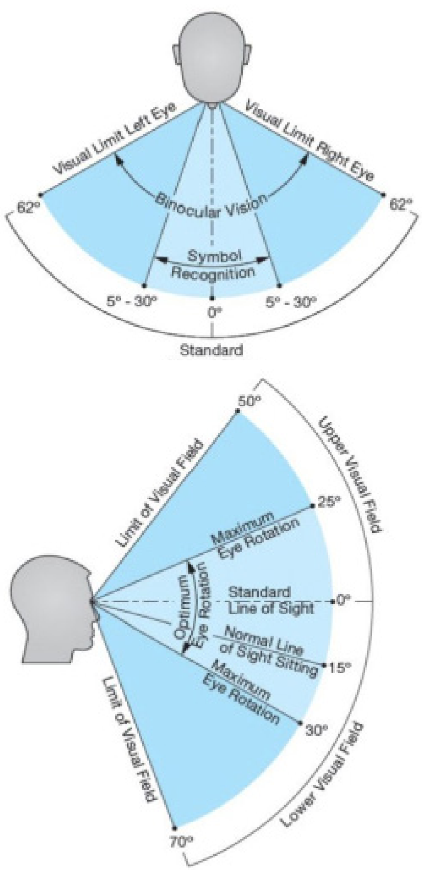


Fig 4. Human factors of the eye

Head Mounted Display

Since Sutherland introduced the first head mounted display in the 1960s, manufacturers and researchers have attempted to improve the technology. For HMD to function, researchers must understand how the human vision system operates. At a high level, vision is the most reliable and complicated sensor in the human body. It provides more than 70% of total sensory stimuli. The eyes capture light through the pupil to the crystalline lens which refracts the light onto the retina. The cones and rod receptors located in the retina send signals to the brain which allows us to perceive our environment (Barfield et al. 1995). Additionally, it is important to understand the human eyes field of view (FOV). Field of view refers to the visual field in humans, specifically the degree of visual angle (180 degrees) when the eyes are stationary (Fig 4). (Strasburger and Pöppel 2002).

Most types of HMD are used for research. Microsoft HoloLens is the only device available as a consumer electronic. The Microsoft HoloLens (Fig 5) is a revolutionary device that gives consumers the

Fig 5. Microsoft HoloLens (2016)

ability to see holograms in their physical environments. Microsoft released the first iteration of this product in 2016 to show that Augmented Reality has a place in the consumer market. The device uses two black and white cameras to identify features in the user's environment. With this data, it can triangulate its own position relative to the space and use that data to ground holograms accurately in front of you (paaron301 n.d.).

The HoloLens was initially marketed as a consumer device, allowing users to run windows applications, Skype with family, play games, and learn with holograms. Despite the attention-grabbing marketing videos, the device price point and hardware limitations (discussed more in the next section) made the product difficult to gain market share. In my opinion, HoloLens was no more than a proof of concept device to spark excitement in developers and designers.

Woodworking

Woodworking is a form of craft where builders transform raw material into objects such as furniture, boats, houses, utensils, etc. Woodworking has been grounded in the tradition to become a master at one's craft.

Apprentice vs. Master

Fig 6. Apprentice by Robert Campbell

Through the mid-19th century, colonial America established apprenticeships modeled after old world practices (Fig 6). An apprenticeship was beneficial for both the worker and employer. A master craftsman would agree to teach a young student as well as treat that person as their own family member. In exchange, the master would receive free labor from the student for up to seven years. By the time the apprenticeship was over that young student would be able to set up their own shop, earn a living, and establish their own apprenticeship for the next generation. It was a way to pass valuable knowledge of craftsmanship down from generation to generation (Williams, 1981).

During World War II and the rise of manufacturing, apprenticeships declined. It wasn't until the 1960's when there was a great revival in the trade. Individuals turned to craft and apprenticeships to question the institution of power in America. From this up rise, the National Endowments of the Arts was established by the government under President Lyndon B. Johnson in 1965 (Bauerlein, & Grantham, 2009). Today, apprenticeships have taken on a different form focused around white-collar workers with a growth from 375,000 in 2014 to 500,000 in 2016 ("U.S. Quietly Works to Expand Apprenticeships to Fill White-Collar Jobs," 2016). Even with the shift towards an apprenticeship for an engineering program, there are still programs focused on the craft industry. A person eager to learn how to build, can seek out a program that will teach them the proper skillset. However, in a metropolitan city like Seattle, it is difficult to take a class with one on one time from a master woodworker. The cost of living in Seattle has made the craft industry less affordable, making masters scarce. A novice's greatest opportunity to learn is to either attend a university or find a local craft program. At the University of Washington (UW), students have access to a woodshop when in the arts and design program. Here, they can use various machines to produce their projects. They can seek help from their classmates but most importantly seek help from John, the woodshop tech. John is the art program's master woodworker. He assists students to solve project problems and ensures they are safely operating the machinery. However, with multiple classes using the woodshop, he is often overwhelmed by the number of questions. Students wait for the right moment to gain his attention when trouble shooting a problem.

It takes years of experience to become a master woodworker. With the limited master woodworkers in a metropolitan city, it is often difficult for a novice woodworker to transition to a master. They dedicate more time to attempt projects on their own and understand that they will endure countless failures along the way.

Craftsmanship

Richard Sennett defines craftsmanship as a skill that is developed through practice and repetition (Sennett, 2009). It can be seen as a way of becoming a master of your own hand (Adamson, 2013). Humans have always had the innate ability to craft new artifacts as their society grows. As technology evolves, woodshops have transitioned from only using hand tools (Fig 7), to incorporating power tools and large industrial machines.


Fig 7. Woodworking Hand tool

The incorporation of power tools has evolved the wood industry to become more efficient and has allowed the reproduction of the same object. Sennett (2009) believes that true craftsmanship is difficult to achieve from the rise of technology. Its pervasiveness deprives artists from learning through repetition. However, Sennett does not define technology.

I argue that woodworkers still have the capability of repetition, but technology has allowed that repetition to be scaled. For example, a table saw can cut a piece of wood very quickly and replaces the need of a hand saw. A woodworker can cut ten times the amount of wood at the same rate it would take to cut one piece with a hand saw.

When performing my field research, discussed below, I noticed minimal use of technology as we know it today. A modern woodworker might use a computer aided design (CAD) program to assist in the development of a furniture piece prior to entering the woodshop. However, as soon as they cross the threshold to their shop, there is no evidence of a modern piece of technology.

Technology Evolution (Efficiency through accuracy)

Bruno Latour defines technology as “society made durable” (Latour 1990), categorizing technology more broadly as any type of tool that can be used for something. Latour was a part of the Science, Technology and Society (STS) community, an avid research group focusing on the influence of science and technology. Jessa Lingel’s research (2016) discovered that artists view the word technology as an internet-based device or application. They did not view the machines found within their workspace or the hand tools used in their craft as a piece of technology. I agree with Lingel’s findings, whereby new machines found within the wood shop are not considered technology. In my opinion, technology is characterized by an object containing a digital component. Wood shop machines are still operated and configured by a human and do not function on their own. Only recently, woodworkers have shifted towards using digital tools to increase their efficiency.

A modern furniture business is set up with efficiency in mind. The goal is to produce multiple pieces of furniture while growing the business. Large machines like the table saw, jointer, and planer, have allowed the business to accurately manipulate the material to achieve the desired results.

Furniture makers like Wendell Castle have taken their shops to a new direction by incorporating a computer numerical control (CNC) robot into their workflow (Fig 8). Amy Cheatle and Steven Jackson’s paper *Digital entanglements: craft, computation and collaboration in fine art furniture production* (2015) documents interviews with members of Wendell’s studio on how they embraced new technology.

Fig 8. Mr. Chip CNC robot

Wendell Castle was a fine art furniture maker for decades. He produced complex, sculptured high-end furniture that pushed the boundaries of the material. In recent years, Castle introduced digital fabrication technology out of necessity to keep up with demand.

The CNC robot known as ‘Mr. Chip’ is a 6-axis carving device used to mill several feet of laminated wood stacks. Mr. Chip is used to do the grunt work of the furniture making process. It has allowed Wendell Castle’s team to become more efficient, resulting in fewer errors while increasing accuracy during the reproduction of custom furniture pieces. This example shows digital technology integrated into a well-known wood studio to improve the craftsmanship. It also shows that a traditional studio like Wendell Castle is interested in using digital technology to increase their capabilities. It’s time for the craft industry to consider alternative, assistive tools to produce high quality pieces of furniture.

Cross Discipline

Augmented Reality has a strong presence in fields like education and entertainment but has yet to be applied to industries like craft. In the Computer-Supported Cooperative Work (CSCW) and Human Computer Interaction (HCI) communities there is a growing body of work exploring the intersection of digital and material practices. Works such as Connie Golsteijn’s integration of craft with physical and digital components (2014), Daniela Rosner’s material practices of bookbinding (2012), and Jessa Lingel’s use of craft to reflect on the Internet of Things (2016) are examples of craft looking to establish the way humans might be able to better interact with technology.

My thesis, a first of its kind, will contribute to those communities through the exploration of Augmented Reality in the woodworking industry. My results focus on a speculative scenario that lean on trends found in current HMD. Since digital technology is non-existent in a woodshop, it was difficult for me to justify introducing a cumbersome piece of hardware. A woodworker would take one look at the device and brush it off. My design speculates that a future HMD could be merely a set of safety glasses needed for the job.

Next, I discuss my process in designing the best AR woodworking tool. This includes my experience with other woodworkers, building in a woodshop, and my exploration with current technology.

Process

For my thesis, I did field research for woodworking and technical research for Augmented Reality. By researching both sides of my thesis simultaneously, I was able to identify the challenges novice woodworkers face in the shop and understand how AR could overcome those challenges.

Woodworking - Research by Design

Over the course of four months, I began researching the implications of applying AR to woodworking in a woodshop learning from master woodworkers and incorporating Research by Design by building a piece of furniture. The difficulty with applying Augmented Reality to woodworking is that woodworking is extremely complex. There is no right method to create something. There are best practices and etiquettes used around the various heavy machines. However, depending on the project, the order of operations varies tremendously. During my research, I had an opportunity to become familiar with the woodshop tools, while also interacting with woodworkers of diverse backgrounds.

Field Exposure

The first month of my research, I worked as a wood fabricator at Pacific Studio. Pacific Studio is a museum fabrication shop (Fig 9) located in Ballard, a Seattle neighborhood. They have conceptualized and built museums such as the Nordic Museum in Seattle, Museum at the Gateway Arch in St Louis, and the Old Faithful Visitor Center at Yellowstone National Park ("Pacific Studio | We Build Stories" n.d.). My job was to apply shellac to the edges of medium-density fiberboard (MDF). Shellac seals the pores of MDF's end grain, allowing a consistent coat of paint to be applied. While the task was tedious, it allowed me to interact and build trust with other woodworkers, an invaluable opportunity.

Fig 9. Pacific Studio fabrication shop

I worked with ten other woodworkers that ranged in experience from a few years (novice/intermediate) to decades (masters). Each one bringing their own skillset to tackle the various fabrication challenges. When I shared with them what I was hoping to accomplish with my thesis, I received a mix range of responses. Some were extremely hesitant by my idea; they didn't like breaking the tradition associated with woodworking. They felt that even using a table saw to cut a piece of wood was too much technology in the woodshop. Others were excited by the idea. asking me a wide range of questions about what AR could do and how it could help them become more efficient in their daily routine. Although the application context is slightly different from museum fabrication and furniture building, the process of cutting wood was still applicable. It was these conversations that motivated me and validated my thesis.

While I was at Pacific Studio, I quickly realized the efficiency differences between my own work and the woodworkers with multiple decades of experience. In a professional fabrication setting, efficiency is extremely important because you are charging the clients the time it takes to manufacture the product. If an employee is not properly budgeting their time, the company can lose clients and money. For example, when I was constructing a simple box for a pedestal (Fig 10); it took me two days to understand the most efficient way to make it. Someone else who has either had experience with making the same boxes, or had experience in similar operations, was more likely to produce the same box in half the time.

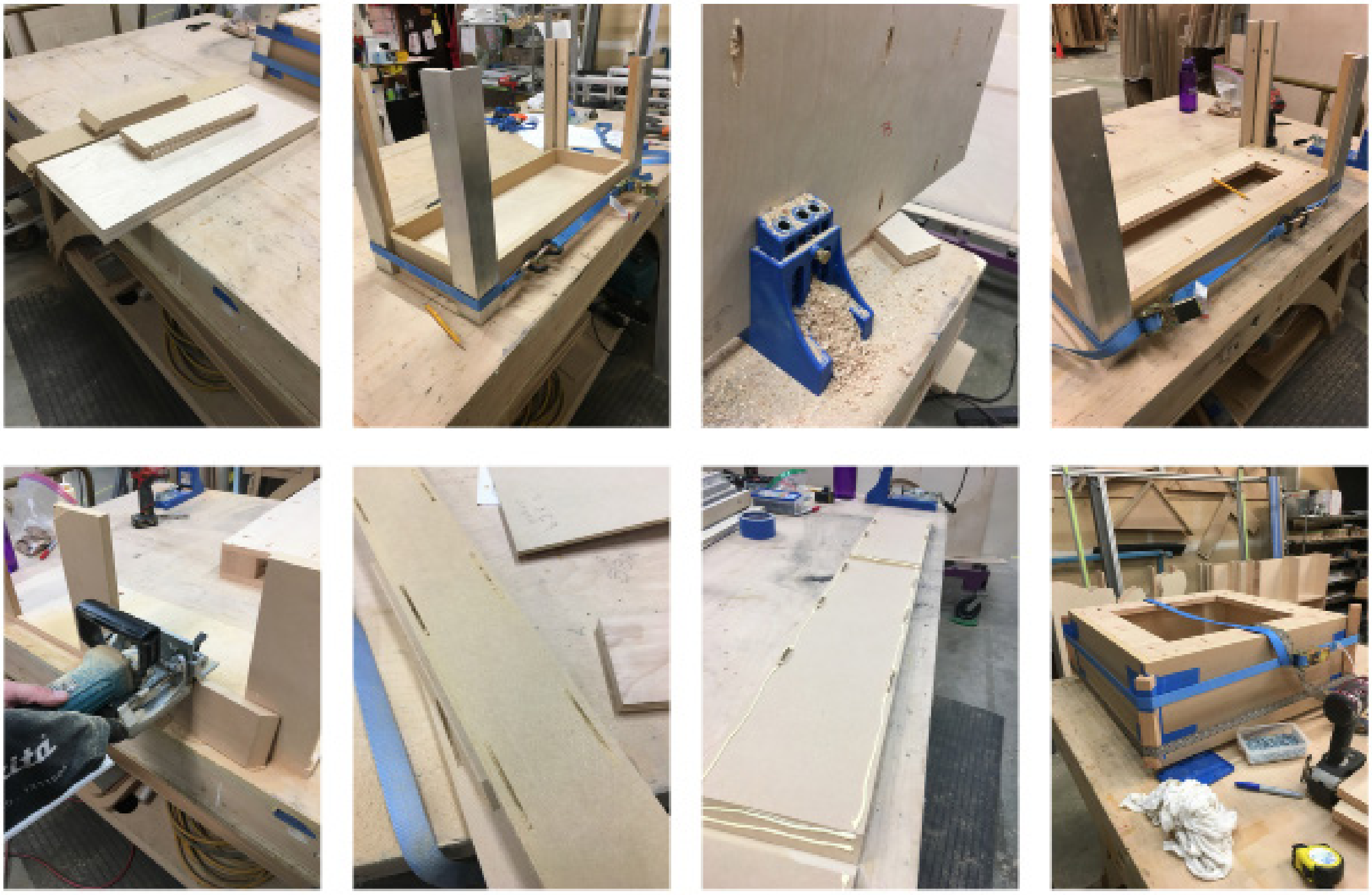


Fig 10. Making a pedestal box

This insight was fundamental for my thesis. Implementing a new technology to a novice woodworker would be more successful than focusing on a master woodworker. A novice woodworker is still trying to understand what works and doesn't work for them. They are more likely to adapt something new which can assist them in becoming more efficient. Whereas, a master woodworker has already discovered the processes that works for them through trial and error over time. This observation was validated during my interactions with the woodworkers at Pacific Studio.

Furniture Fabrication

After Pacific Studio, I continued my field research building a wine cabinet in UW's workshop over the next 3 months. I used this opportunity to evaluate various machine tools found within the woodshop and identify how Augmented Reality can benefit a woodworker. During the build, I realized how complex the process truly is. Not only did I jump between visualizing and executing my cuts, but I also used multiple tools, created various joints, and dealt with the uncertainty of wood. Through this process I realized that a woodworker's goal is to be more efficient in the shop while producing less material waste. I believe that integrating Augmented Reality and its ability to produce accurate measurements into the workflow can help a woodworker achieve that goal.

Fig 11. Plywood

Material (Plywood vs Solid Wood)

Fig 12. Solid wood (walnut)

There are two types of wood commonly found within a large piece of furniture. Plywood (Fig 11) is a manufactured sheet good that is comprised of multiple layers of thin wood glued together. Plywood comes at controlled thicknesses in four feet by eight feet panels. The way the panel is constructed allows for strength and dimensional stability. The quality of the plywood depends on the wood veneer used and the quality of one face of the panel ("Choose the Right Plywood | Popular Woodworking Magazine" n.d.). Since this type of wood is manufactured, it is easy to understand its properties and how it might react to outside forces. Solid wood (Fig 12) is created from a slab of lumber directly from an individual tree. Once cut, they are placed in a kiln to dry. The drying process removes the moisture of the wood as well as increases the strength. The quality of the wood is determined differently than plywood. It can be calculated from the rarity, visual appearance, species, thickness, or whether it is a hardwood vs softwood ("19 Tips for Buying and Using Rough Lumber | Popular Woodworking Magazine" n.d.). Because solid woods are constantly expanding and contracting due to moisture in the environment, it is often difficult to predict how the wood will react after it is purchased.

To remove any uncertain variables, this thesis focuses on breaking down a sheet of plywood. The act of breaking down plywood is achieved by taking a large sheet and successfully producing smaller parts. By focusing on plywood, the augmented reality device will be more successful at identifying the material. Due to the complexity of the various hardwoods, it would be difficult for the technology to successfully analyze the piece of wood being used. I believe that in the future this analysis will be possible within AR, but until then, plywood is the most accurate.

Visualization Phase

Measure twice, cut once is a term often used when woodworking. A woodworker spends their time shifting between visualizing the cut and executing the cut. When visualizing, they are trying to identify the best approach to make a part. In this phase,
I assume that a woodworker has already designed or acquired plans for a furniture piece, printed these plans, purchased their materials, and are ready to get started.

Visualizing is critical to the success of a project because there are multiple ways to achieve the same result. When an error occurs, it is often a simple calculation mistake caused by the woodworker. A novice can be found visualizing more often than a master woodworker. They often measure more than once to make sure their marks are correct. Although they might feel confident in their mark, they might still produce errors due to other factors not considered.

Execution Phase

During the execution phase there are many tools available in a woodshop, each performing a specific task. During my fabrication of the wine cabinet, I evaluated each tool. I describe their purpose and highlight where Augmented Reality could enhance the experience at each machine.

Table Saw

The table saw (Fig 13) is the most important tool in a woodshop. It can produce a wide range of cuts with various sized boards and sheets of wood. It is a precision cutting tool that requires proper set up and maintenance to perform accurately. The table saw has two important components to it: the blade and the fence. The blade is always fixed at a specific location. It can be raised to a certain height and angled. It can spin towards the operator to make long straight cuts. As opposed to the blade, the fence is movable. It is located to the right of the blade and can be positioned close or far from the blade. The distance between the fence and the blade is what a woodworker measures to produce their final cut.

A woodworker can perform two types of cuts; rip-cut or crosscut. A rip cut is made when you cut with the grain of the wood. It is a smooth cut that is made along the length of the board. A crosscut takes place when you cut across the grain. When making a crosscut, an auxiliary fence is used to help stabilize the piece of wood ("Woodworking Essentials: Table Saws | Popular Woodworking Magazine" n.d.).

This thesis focuses on rip-cuts as they are the most common. The table saw and its versatility provide great opportunity to implement Augmented Reality. This machine is often used as the finishing tool to develop the parts needed for furniture. Accuracy is important because simply cutting incorrectly by 1/16th of an inch can render that part unusable for the project. Depending on the cut to be produced, there are often errors when setting the fence.
A woodworker can measure the distance incorrectly, not accounting for the thickness of the blade, or feeding the wood poorly through the tool. Augmented Reality has true potential to improve efficiency while at the table saw and I aim to show that experience in my design.

Fig 13. SawStop Table Saw

Bandsaw

Fig 14. Jet Bandsaw

A versatile tool in the woodshop used to cut thick lumber, curves, and irregular shapes is the bandsaw (Fig 14). A bandsaw contains two wheels that hold a band of blade. This blade cuts downward into the table of the tool. A bandsaw comes in various sizes depending on the wheel sizes and types of blades. Different blades allow for different radius cuts and it is important to understand those radiuses when making irregular cuts ("Band Saw Tool School | Popular Woodworking Magazine" n.d.).

A common mistake caused when using a bandsaw is not understanding how the bandsaw operates and therefore, making cuts that are completely off from the lines drawn on the material. When using this machine, a woodworker could use AR to visualize the projected path of the blade to understand when they should apply force or adjust the material to accommodate the movement. In addition, AR could be used to visualize the various radiuses associated with the blade.

Although this tool has a lot of potential for AR, it is a relatively easy tool to understand. If a woodworker is following a mark on their material and is not paying attention, they may make a mistake and cut through their marks. But with a little trial and error and understanding where to not place their hands, the bandsaw is a straightforward tool.

Miter Saw

A miter saw (Fig 15) has one task - to make long sticks, into short sticks. It can swivel left or right to make miter cuts. A miter cut refers to an angled cut, typically 45 degrees, where two beveled pieces of wood come together to form a corner (Noll 2009). Miter joints can be found in picture frames, house moldings, and house framing. Miter saws are often found on construction sites because they are portable and will quickly make long beams into shorter beams. This tool can also be referred to as a chop saw because the action is a downward, chop motion.

Due to the simplicity of the action this tool performs, AR would not be a necessary addition to this tool. A woodworker can simply mark their cuts on the board, align the blade and perform the cut.

Fig 15. DeWALT Miter Saw

Jointer & Planer

A jointer (Fig 16) is an important workshop tool when working with hardwoods. Hardwood boards often require work to make them flat and parallel. The blade on the jointer is located on the bottom and cuts the underside of a board. A woodworker passes a hardwood board across the blades to remove material, ultimately making it flat. After one pass on the machine, a woodworker can visually see where the material has been removed, and where it has not. Multiple passes are common. A woodshop contains both a jointer and a planer, they are a team. Once a side is flat from the jointer, it is taken to the planer which can make the opposite side flat and parallel to the first side.

The planer (Fig 17), in a sense, is a jointer turned upside down. The blades are located on the top. The planer is also used to determine thickness. By taking multiple passes through the planer, a woodworker can turn that board into its desired thickness. Once that thickness is achieved, it is brought back to the jointer and turned on its side. The woodworker now focuses on one edge

Fig 16. Powermatic Jointer

Fig 17. Powermatic Planer

of that board making it flat and perpendicular to the flat faces. This action is where the name jointer comes from. By making an edge flat on two separate boards, they can be placed together to make a secure joint.

Like the miter saw, the action performed on these two tools would not necessarily be enhanced by AR. Each tool gives visual and audio feedback when in use. A woodworker can see marks directly on their material from where the blade cut vs not cut. They can also hear when the machine is cutting too little or too much material. The only potential opportunity which AR could provide, is to show the thickness of the board when it makes a pass through the planer. But a woodworker can simply use a caliper to measure the thickness after each pass.

Throughout my research I quickly jumped between the visualize and execute phases. Although I have prior experience, I still relied heavily on my ability to plan. Along the way I made various mistakes because I forgot to factor in the thickness of the blade or referenced the wrong measurement on my drawing. It was a frustrating process but allowed me to understand the value of measuring twice before cutting. By removing the human element of error, I saw an opportunity to increase the woodworker's efficiency using Augmented Reality. What if, it in the future, we could feel confident and simply measure once, cut once?

Augmented Reality Research

As part of my research on AR, I explored the mobile phone and head mounted device platforms. I used this opportunity to understand the current trends and design affordances on each platform. By exploring the difference, I was able to draw a conclusion as to how I would situate my augmented reality experience for woodworkers.

Mobile AR Platform

Through my woodworking research, I wanted to find a way to measure and mark in augmented reality. I explored phone AR apps that focused on measuring. Three apps stood out, IKEA Place, PLNAR, and IOS Measure.

IKEA Place (Fig 18) is an app that lets you see IKEA furniture in the context of your home ("IKEA Place" n.d.). Users select a product and it will display that product at real scale on your mobile phones screen using the camera. This tool allows you to 'see' if the product will fit in the environment and match your décor prior to purchasing. This app helped me establish the ability to see a 3D model of furniture. When designing furniture, it is important to make sure the proportions and scale are correct before you execute.

PLNAR (Fig 19) is an app that helps measure interior spaces ("PLNAR" n.d.). Users simply point a mark at corners in their room to define walls. As they move from point to point along the floor, the app constructs a blueprint of your space. By quickly mapping out your own space, you can use this data to contact contractors or create your own DIY projects.

iOS Measure (Fig 20) is like PLNAR but is focused on smaller measurements. Users can define points in space that correlate to physical objects and a calculation will appear ("*Use the Measure*

App on Your IPhone, IPad, or IPod Touch" n.d.). Although this is a nifty tool, it is currently inaccurate. It often will give different measurements for the same object or if you change your position it will measure incorrectly.

Even though I don't believe mobile AR is truly Augmented Reality, these apps show the need for new ways to perform measurements of physical objects. Each example helped influence my design decision when using AR in a woodshop.

Fig 18. IKEA Place

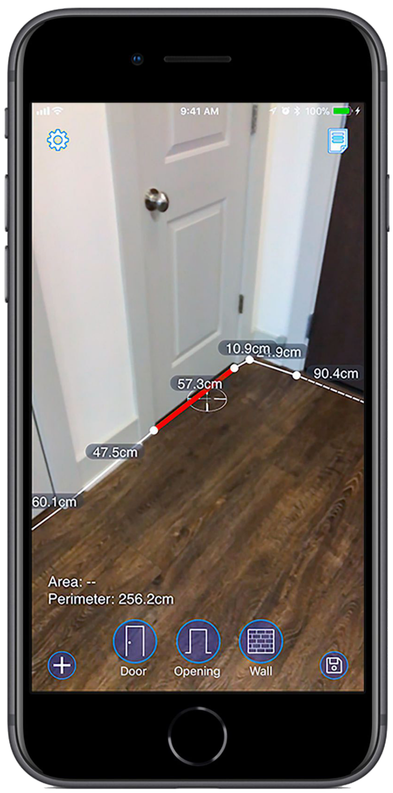


Fig 19. PLNAR

Fig 20. iOS Measure

Fig 21. Microsoft HoloLens 2

Head Mounted Device Platform

The best form of head mounted device for AR is Microsoft's HoloLens. Although I view the HoloLens as a prototype, I am still fascinated by how the device works and how to develop experiences for it. I spent time reviewing Microsoft's Mixed Reality tutorials to understand the coding process for the device. I followed scenarios that dealt with placing objects in virtual space, creating spatial mapping, and input various gesture controls (keveleigh n.d.). By working directly with the HoloLens and these tutorials, I gained an appreciation for the technology inside the device. It allowed me to understand the various affordances and hardware considerations needed for a good AR experience.

During this research period Microsoft announced HoloLens 2 (Fig 21). They took the feedback provided from the first generation and improved components such as ergonomics and immersiveness. They integrated new hardware, such as the AI camera, which allows the device to see better and identify objects in the physical world. They shifted the target audience from consumers to business focused users; a user who's daily job is hands on or out in the field away from a computer at a desk ("*Microsoft at MWC Barcelona: Introducing Microsoft HoloLens 2*" 2019). This shift in target audience, helped ground my thesis around an individual who is in a tactile industry, woodworking. Now more than ever, context is critical. A designer can focus on a specific work environment and tailor a solution for that space. A soldier using HoloLens 2 in the military will have a much different experience than a doctor in an operating room.

Unfortunately, designing a prototype for the HoloLens didn't feel practical for me. It has many hardware limitations such as, limited field of view, occlusion issues, and ergonomics, each drawing away from a good user experience ("*The HoloLens Isn't as Great as You Think—At Least Not Yet | WIRED*" n.d.). However, as the HoloLens and other AR devices evolve, it's time for designers to understand the context of AR and how it can assist these users in becoming more efficient. This proof of concept enables me to imagine a speculative future where the hardware is suitable for woodworkers.

Fig 22. Microsoft HoloLens 2 Marketing

Prototyping

The purpose of a prototype is to take ideas from a designer's head and place them on a tangible surface. Prototypes can be done on a device, on paper, or in a 3D environment. Prototypes can range in quality depending on the stage of the process. Prototyping for Augmented Reality is a new challenge that designers are still conceptualizing. AR combines both the physical and digital world. Therefore, it is difficult for a designer to find ways to display digital content spatially situated in their environment. Traditional designer tools like Adobe Illustrator or Sketch, aren't suitable for AR prototyping because they don't allow you to position digital information in 3D space. An alternative, low fidelity method, is paper prototype which is physically drawing the experience on paper and placing that experience in the environment. This approach could work, but there is difficulty when there are interactions that are suspended above a surface. This thesis explores an alternative prototyping method. I could have created a paper prototyped in a woodshop and captured images of the experience, but I wanted to integrate a new technology. I quickly turned to prototyping in Virtual Reality to "paper prototype" in a 3D environment. There are various virtual reality tools on the market (Gravity Sketch, Maquette, Google Blocks, Tilt brush) that give the ability to manipulate 3D shapes to construct various objects and virtual worlds. I chose to use Maquette (Fig 23) as my prototyping tool because it allows creation of 3D objects along with 2D elements, something that the other programs lack.

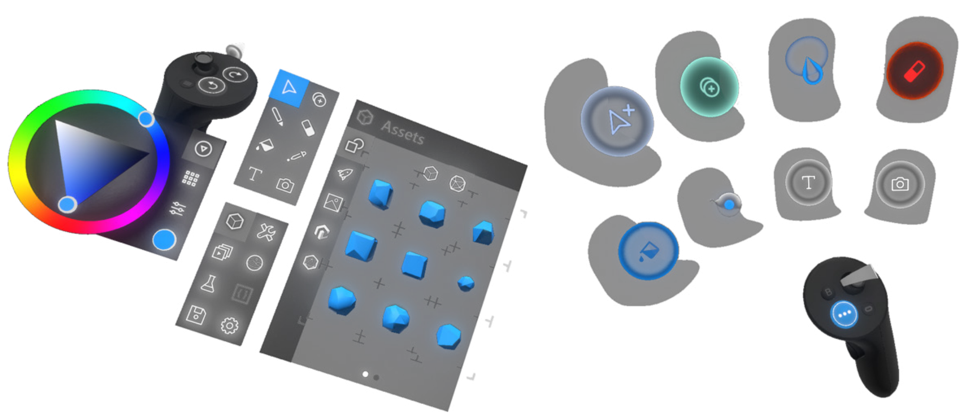
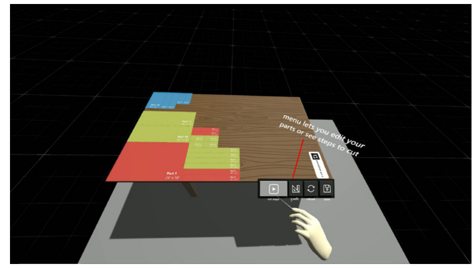
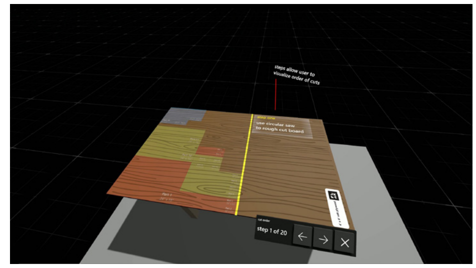
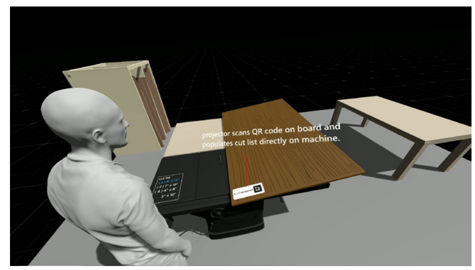


Fig 23. Microsoft Maquette

Virtual Prototyping







Maquette (Fig 25-27) is a tool developed by Microsoft ("*Microsoft Maquette Beta* – Home" n.d.). Although Maquette is in the early stages of development and lacks some prototyping features, it is a virtual reality (VR) tool with a blank canvas. Creating an Augmented Reality experience with a virtual reality tool initially proved difficult because I had to create the environment from scratch. Yet speed is essential for prototyping to quickly visualize ideas and gain feedback. Abstracting the environment was the best course of action, allowing me to remove the distractions and focus on the interaction. I worked with a sheet of plywood, and a table saw model and constructed User Interface (UI) elements on top. I used a featured in Maquette called the slideshow. It allowed me to step through each design decision quickly. It was fun to work in this virtual reality environment. The results of the program allowed me to share my ideas with my peers for valuable feedback.

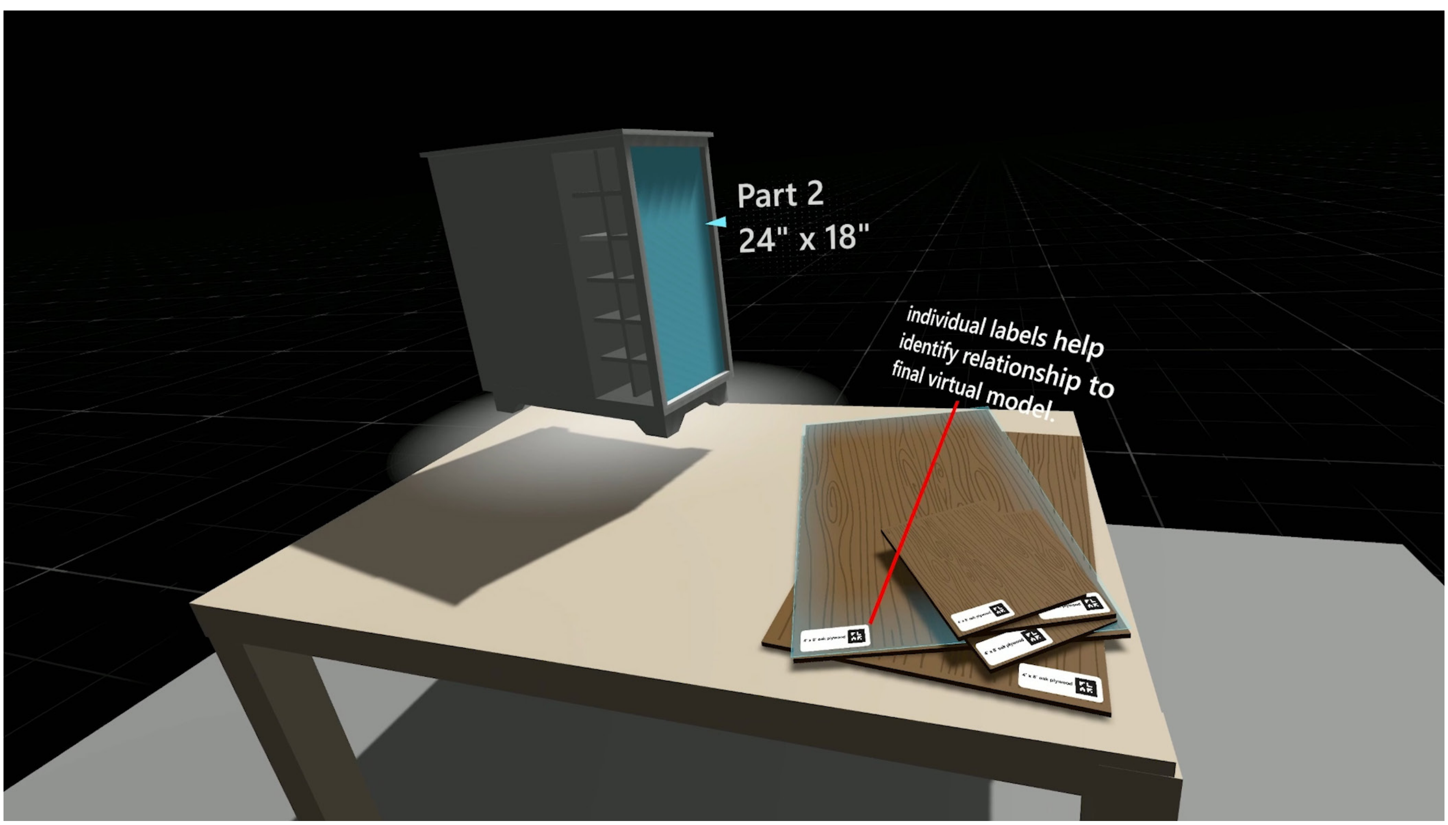


Fig 24-27 . Screenshots from Maquette

Technical Prototyping

The final stage was to create a technical prototype – one that demonstrates my design. My final design is highlighted through a three-minute video. The process of understanding the programs needed was more complicated than I initially anticipated. In unison with building the wine cabinet, I spent time capturing footage in first person perspective and manipulating it in various software programs. I referenced various YouTube videos that would help me understand how to track surfaces, create 3D cameras, and insert virtual models. The end video uses a combination of Adobe After Effects, Adobe Premiere Pro, and Cinema4D. After Effects (Fig 28) proved to be the most difficult tool to use because tracking a piece of wood was not as straight forward as tracking a mobile screen (a common task used in After Effects). The program kept losing the surface of the wood and I would have to manually adjust the track. It was a long, tedious process, but the results were worth it.

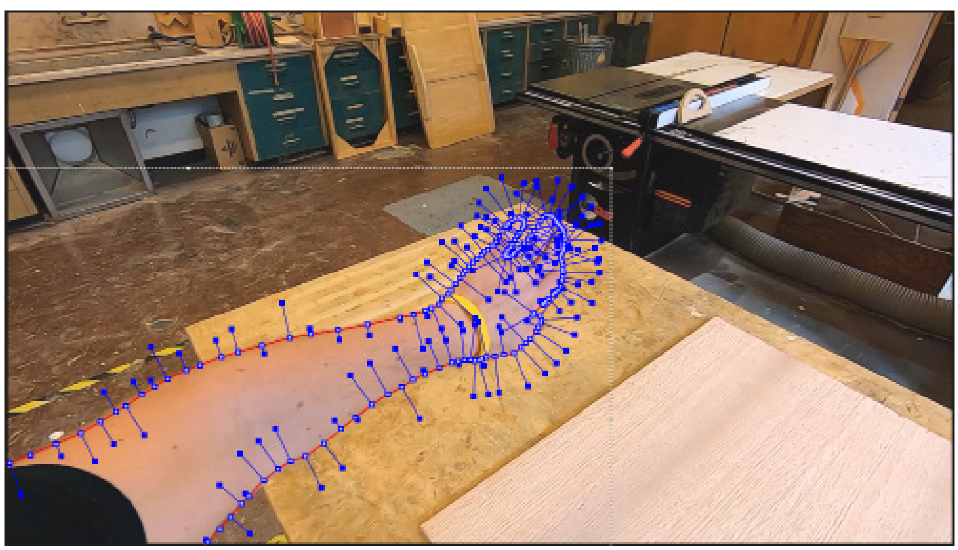


Fig 28 . Screenshots from Adobe After Effects

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Results

Visualizing Augmented Reality today can be a difficult task. One approach is to prototype an experience directly on a physical device and capture that experience in action. The difficulty with this approach is a designer must understand how to use Unity, a coding software used to build AR and VR experiences. Currently, Unity is difficult to learn, and hardware limitations of current devices prohibits creating a prototype using an actual AR head-mounted device. As a designer, I have speculated a woodworking scenario using current technology devices but portrayed in the future through a video.

To convince a woodworker to add a new digital tool to their workflow, it must not complicate their current process. Today's technology simply won't suffice. The technology needs to be a secondary aid to the woodworker. They need to be able to focus when operating dangerous machines. If the technology is distracting to the woodworker, it defeats the purpose. My video (Fig 29) is a conversation piece to portray Augmented Reality in the context of woodworking.

Fig 29 . Screenshots from design video found on Vimeo

Video Prototype of the Design

My design is established in a short video prototype, depicting a demonstration of key moments in the interaction experience sequence. In the video I highlight six design concepts. Each concept is elaborated below with my rationale behind the design. I also establish which parts have been speculated and why those speculations are necessary for an ideal user experience. The first speculation is that an AR device is small, no larger than current safety glasses.

Fig 30 . Hand Off

Hand Off — label allows AR to see

This concept (Fig 30) focuses on a way for the head mounted display to know that a sheet of plywood contains data. The smart label would contain an Augmented Reality QR code allowing the device to scan and project the associated contents. There are two paths to acquire the required QR code: through SketchUp or purchasing project plans.

Sketchup is a CAD program that woodworkers like to use to design and model 3D representations of their furniture projects. Currently, SketchUp contains an extension called CutList that produces a printed list of all the parts needed for the model (“CutList | SketchUp Extension Warehouse” n.d.). A woodworker can print the list to understand the required material and associated measurements. The difficulty with this extension is the translation between 3D model to a 2D printed list. A novice woodworker might find the list confusing with the various measurements. They must look at their blank plywood and mentally visualize the parts on the sheet. My proposed solution would have a similar extension which could produce both a cut list and an AR component to visualize directly on the material. Alternatively, if the user is not familiar with programs like SketchUp, they could purchase project plans from an online source. The woodworker simply attaches the label onto the plywood, as instructed, and the hand off is complete.

I make a few speculations in this label. I assume that the label is the best way to provide the data to the plywood. As discussed, prior, this hand off can be used by the power of the artificial intelligence (AI) camera found on HoloLens 2. This camera can understand what the device is looking at and follow its journey through the cut process. In part 3 of the video I discuss previewing the cuts. I assume that after one part of the wood is cut, the AR device understands the next part to reference sequential cuts.

Projection — visualize the parts

One of the most difficult things to grasp as a novice woodworker is the amount of material to purchase in relation to the parts needed. When I was making the wine cabinet, I over purchased my plywood by one and a half sheets. AR can solve this error by allowing the woodworker to visualize the various pieces directly on the material. The AR device would display the parts directly on the material to maximize the yield of the board (Fig 31). This reduces the amount of waste by creating larger scrap pieces for future use. Additionally, by visualizing the parts directly on the material, a woodworker can see the grain associated with that piece. Visual aesthetics are just as important as structural integrity. For instance, if a part is placed in a location that has a knot; the woodworker might decide to

Fig 31 . Projection

reposition it. They can virtually move that part into another location on the board and the device will adjust the order of operations accordingly.

Like the first scenario, I assume that the AR device can see the sheet of wood. This is important because accuracy is key. The goal is to help minimize the waste created during cutting. If the device cannot establish the edges of the sheet, it cannot correctly project. Since the plywood has sharp edges, the device would be able to distinguish the board as a plane and project onto that. The only difficulty it may have is when the plywood is set onto a wood table, as shown in the video. Current technology may find the similarities of tone difficult to differentiate. Secondary, accuracy in measurements must be key. I portray that a part is at a specific dimension. If those measurements are off, there would be an opportunity to not trust the technology. In addition to the part dimensions, each white line should be 1/8th of an inch to symbolize the blade thickness. Accounting for the blade thickness is important because it must be factored into the accuracy of the parts. If the measurement is off, then the parts will not be accurately cut with the table saw.

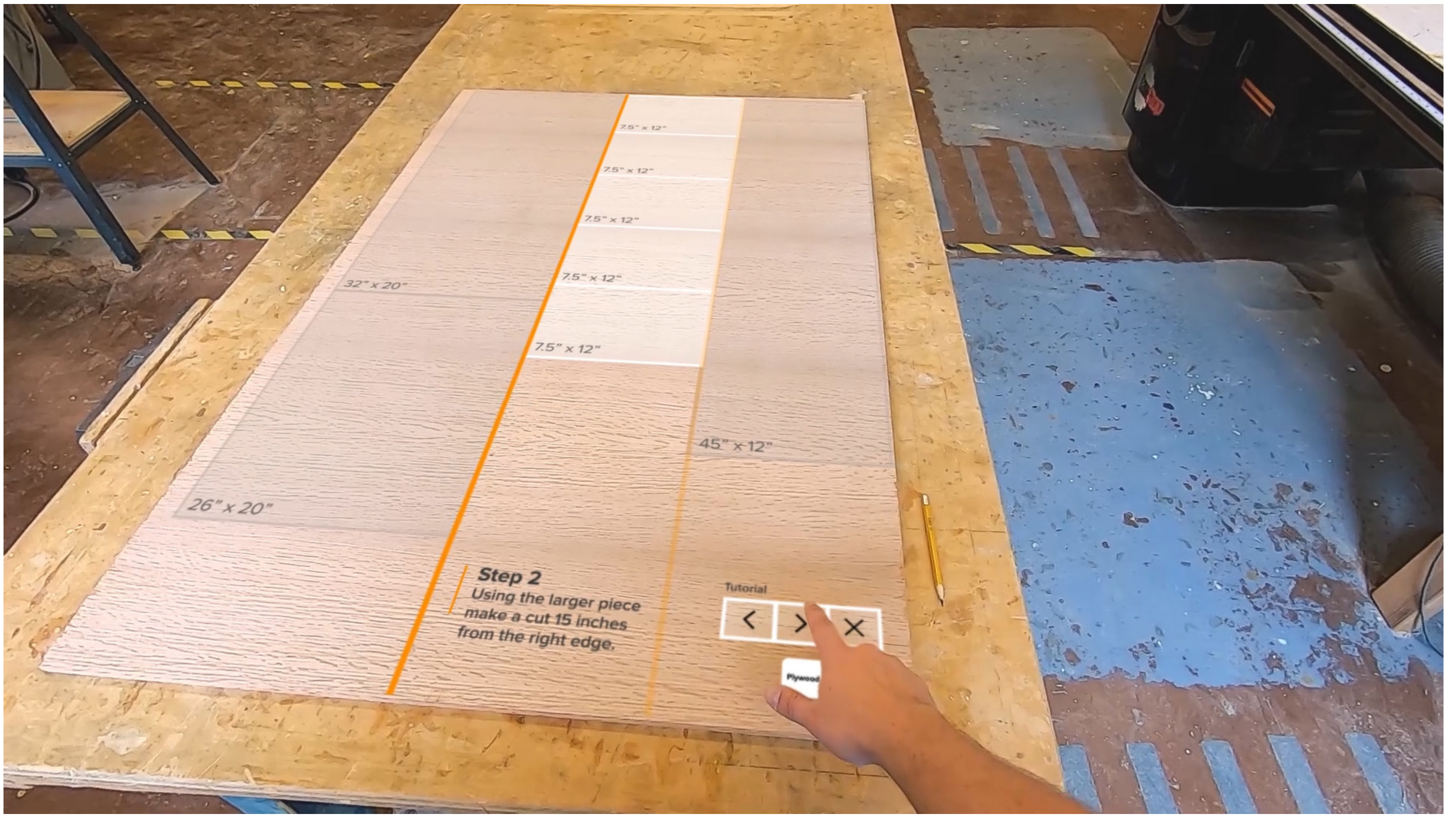

Fig 32 . Tutorial

Tutorial — preview the cuts

To maximize efficiency at the table saw, it is important to know the order in which the parts will be cut. If I have a list of six parts all with the same dimension, it would be unwise of me to set the fence to that first dimension, move it to another dimension, and back.
I could easily set the fence to the one dimension and cut those six parts out at the same time. Currently, a woodworker must make this mental leap on their own and keep track of the various parts and what parts are completed or not. AR has the ability give the woodworker a visual representation (Fig 32) directly on their material prior to approaching the table saw. It allows them to step through the order of operations to understand the various movements. This will remove any guess work while at the table saw, allowing them to focus on the cut. By focusing more attention on the planning phase and removing the guesswork, woodworkers can now become more efficient and focus their attention on the problem solving rather than the basic measurements.

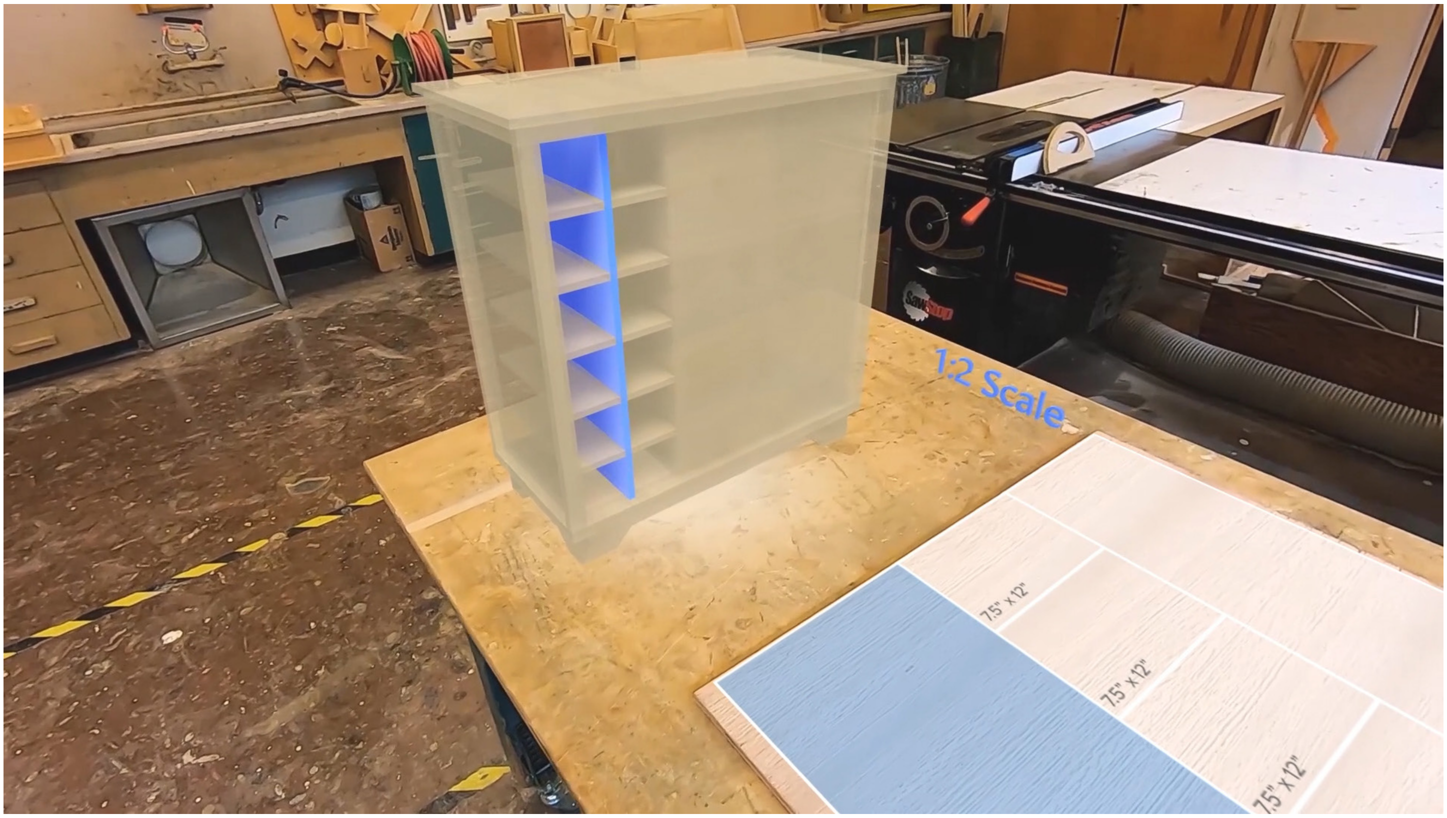

Fig 33 . Virtual Model

Virtual Model — understand the context

Abstracting parts onto a sheet of material can become confusing as to how those shapes are related to the final furniture piece. In the past two scenarios, the AR projections have been flat on the surface of the plywood. That method is good when dealing with flat stock but eventually those parts will be assembled into a three-dimensional form. As previously mentioned, visual aesthetics of the wood grain is important. This design allows the woodworker to move parts to accommodate more pleasing wood grain. But this feature is only useful if the part is external facing. There are instances where parts are contained within the piece and the surface will never be seen by someone. In this case, adjusting for the wood grain is not necessary.

One unique feature of augmented reality is its ability to project holograms (Fig 33) in the physical world. These holograms can be placed on surfaces, scaled large, grounded to the floor, etc. Currently, woodworkers are constrained by using CAD programs on a 2D screen to simulate 3D objects. The difficulty with this workflow is the understanding of scale of the 3D model that has been constructed. A measurement in CAD is difficult to understand because it is contained within the computer screen. Augmented reality can break that constraint and display the 3D model at full scale directly in front of you. Now, a woodworker can understand the proportions of parts on their furniture piece. They can touch the projected part on the plywood and a virtual model will appear with the part highlighted in 3D space. They can quickly understand how that cut relates to the final model and if the wood grain truly matters.

One of the most frustrating and difficult aspects of augmented reality is the technical limitation of occlusion. As Tian et al. states, “occlusion occurs when the real objects are in front of the virtual objects in the scene. Without occlusion handling, users will have the misconception that the real object is further from the viewpoint than the virtual objects when the virtual objects are occluded by the real objects in the scene” (Tian, Guan, and Wang 2010). On modern devices such as the Hololens, occlusion does not take place. When a user has a hologram in front of them and they move their hand across to rotate that object, ideally the hologram would appear to go behind the hand. On Hololens, this does not happen. The user’s hand goes behind the hologram and distorts the illusion. I understand the difficulty of incorporating occlusion in technology today, but I am confident that this problem will be addressed as AI becomes incorporated into AR devices. In my design video, I have occluded objects as they should appear. When the users hand goes in front of the virtual model or UI, it appears as those digital components are behind the user’s hand.

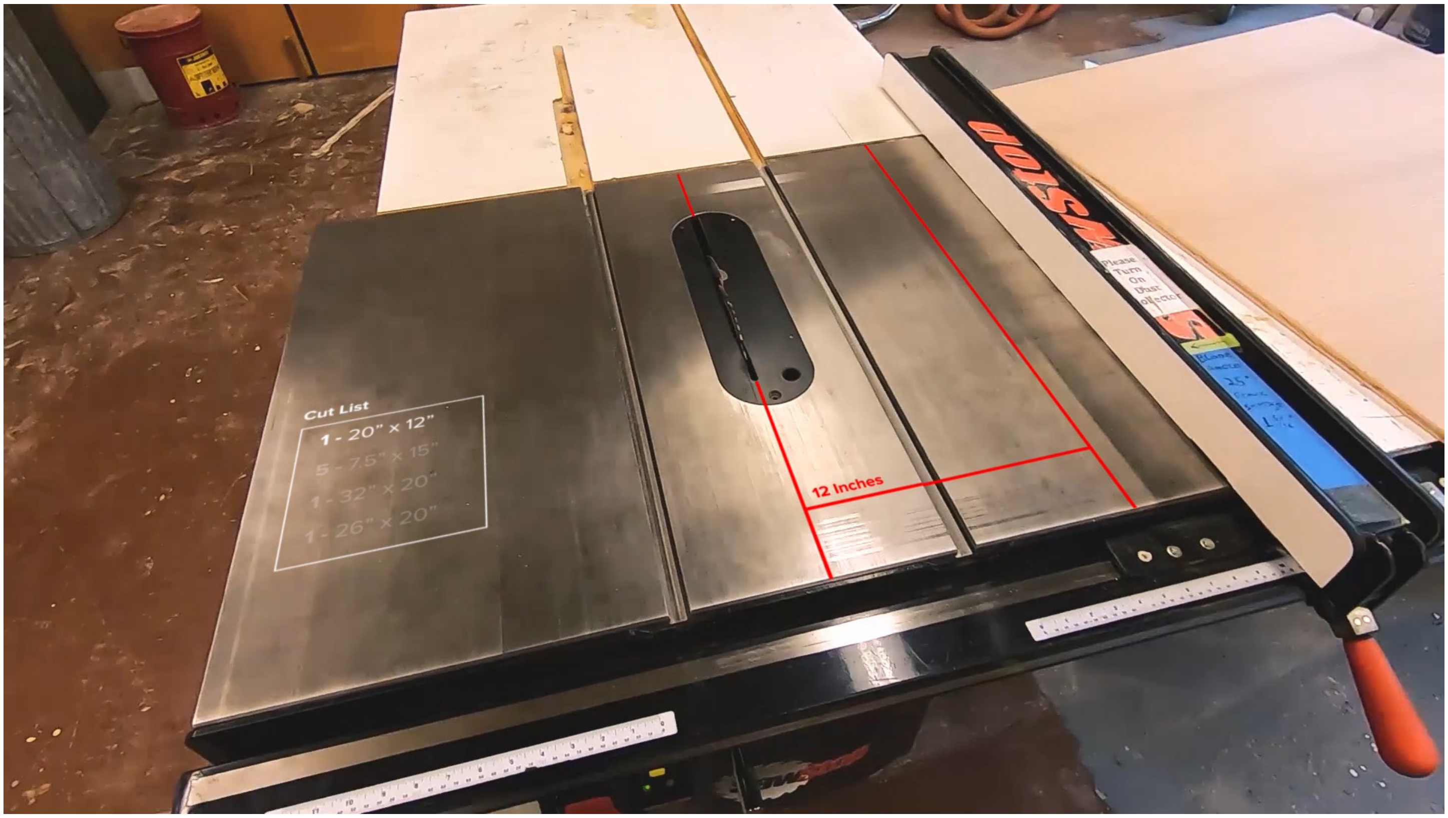

Fig 34 . Visualize

Visualize — setting up the cut

The previous four scenarios of augmented reality apply to the planning stages of woodworking. The next two examples (Fig 34) focus on the execution aspect while operating the table saw. The table saw can be intimidating for a novice woodworker. There are horror stories of wood being thrown at the operator or accidents involving fingers. Although it is impossible to cut fingers off with modern tools, accuracy and caution is needed while using this machine. Using the tutorial and understanding the order of operations at the table saw, the user will be able to confidently set up the saw for their first cut.

Commonly, a woodworker will write down a cut list and keep it next to the saw while they work. The cut list is a valuable piece of paper containing each measurement needed and how many parts of each to make. A paper cut list is likely to be lost or placed on a table nearby. The woodworker's efficiency is compromised because after each cut, they must turn to the cut list to receive the next set of measurements. Although a small adjustment, it reduces valuable time while operating the table saw.

This scenario gives the ability to see the cut list directly on the table saw bed. The information is directly in the view of the operator and easy to access. When selecting this first cut, lines are projected to adjust the fence. One line is shown aligned with the blade and the second is shown where the fence should be to establish the dimension. The operator simply adjusts the fence to line up with the line and the AR unit will confirm when it is in the correct position. As the woodworker moves through the cuts, the cut list will keep track of their progress and project new measurement lines as needed. There are several assumptions I make in this scenario. I rely heavily on the AI camera found on Hololens 2 to be able to detect the table saw.

My design is based on a specific table saw called the Saw Stop. This is a modern table saw that contains specific characteristics. Using the knowledge acquired by the AI camera, as the user walks up to the table saw, it will detect and automatically project the cut list to the left of the blade. As the user selects the first cut, the device knows where the blade is based off the table saw model. From there it can project the fence dimension to the right of the blade. As stated, accuracy is critical. The device must project the measurement line in the correct location for the system to be functional to the woodworker. The room for error is so small that 1/16th of an inch off, and the piece is unusable.

Fig 35 . Focus

Focus — AR hides when working

The use of AR can provide another layer of distraction to the woodworker while operating heavy machinery. Although theuser interface I have designed is minimal, it could provide a point of focus when engaging in a cut. To combat this problem, I have designed a simple solution (Fig 35) to hide the AR as soon as the machine is turned on. The audio queue from the table saw indicates when the UI should hide and turn on. At this point, the woodworker's focus should be directly on the cut itself and not on the cut list or measurements.

The scenarios described above help illustrate how AR could be incorporated into a typical woodworker's workflow. It allows the viewer to understand each design consideration from the eyes of a woodworker.

Reflection

There is a compelling case to integrate AR into the woodworking practice. With the introduction of AR, those novice woodworkers can gain insightful information directly in a woodshop. No longer do they have to wait for a master's attention to ask for advice on a simple cut. They can put on an HMD and be self-sufficient on their task. They can still reach out to the master if they need help, but this tool would allow them to attempt a cut with confidence. My final design video prototype is an illustration of applying AR to a woodworker's scenario and can initiate a conversation around the potential future of AR. The demonstration carefully considered the way humans can perceive their natural surroundings by drawing from James Gibson's book The Ecological Approach to Visual Perception. Gibson states that human perception is contextual to the environment the viewer is situated in. They can draw enough information by the pattern of light bouncing off objects in space and back into the cornea of the eye (Gibson 2014). To develop a successful AR interaction, the designer must understand the context and environment the user is in. AR is no more than a contextual illusion of light bouncing between glass plates and into the eye of the viewer.

For some, this cross over between woodworking and augmented reality seems odd. These two opposing industries were chosen for a reason. A traditional woodworker is an individual that is least likely to purchase an AR device. If I can design a scenario that convinces them to integrate AR into their workflow, then it shows that AR has a purpose in this and similar fields. My goal with this video was to show that this new digital tool should be designed as a companion to the user. Woodworking is all about making decisions, learning from mistakes, and improving the craft. If digital technology diminishes the user's experience, then it is too involved. The results developed in this thesis should continue to contribute to the research made in the CSCW and HCI communities. As technologies continue to advance, we must understand how these new technologies can be applied in all aspects of life. Sometimes it is difficult to grasp the implications of new technologies until we try them. By placing technology like Augmented Reality in an unfamiliar context of woodworking, we can begin to understand new capabilities that we previously did not conceive.

Insights

This thesis has provided me the opportunity to design an AR experience for a completely new area – the design of Mixed Reality experience where design takes the shape of holographic elements in the line of sight. I discover new ways of 'paper prototyping' using virtual reality, I learned new augmented realities programs, and I uncovered new digital design principles and considerations while working in physical space. With my background of industrial design and professional experience in digital design, I was able to combine the two disciplines in developing a new interaction for woodworkers. I learned the challenges of rotoscoping in After Effects, and the attention needed to make convincing motion graphics. I learned a lot about the current state of augmented reality, such as the current hardware limitations, the need for improved field of view, design affordances when creating the UI, and various technology programs needed to accurately portray AR. This process has created personal excitement for this future industry and its opportunity for designers to create work changing experiences.

Future Directions

Future directions of this work would focus on illustrating other elements of a woodworker's experience like the ability to rearrange pieces depending on the woodgrain or additional interaction and alterations during the execution phase. What if they change their minds on a certain proportion of the piece of furniture they are making? Could they make design decisions with the holographic 3D model and the projected parts automatically adjust? Seeing scale of their final model with AR is extremely powerful. Currently, I show a static representation that the user spins; however, I would like to explore other 3D rendering capabilities. What other options could this 3D model provide, what other information can it give to the builder? What happens after all the pieces are cut on the table saw? Does it show you how to create joints that are perfect the first time? What if the woodworker makes a mistake, can it help identify and give suggestions on what to use that part for? How does the system work on other tools? How does it handle hardwoods?

These are the questions I would love to continue to explore and address. This is the excitement of designing new technology in an industry that has yet to be explored. There are so many questions to answer and situations to solve. By breaking down these questions, you can begin to understand what master woodworkers are able to understand through their years of experience.

Conclusion

To design a successful Augmented Reality application that support human activities, one must understand the context of the tasks and activities that people engage in – this includes aspects of the physical and social environment the activities are situated in, the goals, constraints, and dangers inherent in the activities to be undertaken, and the various perspectives, knowledge, and experience of the individuals that engage in the activities. It is through this context that I was able to create a convincing depiction of a world in which a woodworker uses AR to learn how to break down a sheet of plywood. Without the context of the wood shop, table saw, plywood material, or a piece of furniture, such an application would not be possible.

Designing for augmented reality was challenging. Designing for Mixed Reality is a design practice that is in its formative years where designers and engineers are still understanding its potential. A head-mounted device, like the Microsoft HoloLens, is a wonderful proof of concept seeking excitement from designers and engineers. Augmented Reality has tremendous potential when the experience draws on human's behavior. By observing the way an individual interacts with their environment, a designer can apply visual structure to key operations to support interactions hands-free and precisely aligned in the line of sight. This new display ability overcomes many representation limitations that were inherent in visual systems of the past. As we continue to explore and push the future of AR, we must not lose sight of who will be wearing the device. Our focus must remain on the uniquely experienced individual who applies knowledge, skill, and experience to the task at hand. When we keep them at the center of the design of Augmented Reality, AR has the potential to assist and propel their interactions to become more targeted, precise, and efficient than ever.

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