APPLICATION OF AUGMENTED REALITY IN THE CONSTRUCTION INDUSTRY

by

MUSSIE GEBREGIORGIS GEBREMEDHIN

B.S., University of Colorado, 2018

A thesis submitted to the

Faculty of Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

Master of Science

Department of Civil, Environmental, and Architectural Engineering

2020

Committee Members:

Paul Goodrum

Matthew Hallowell

W.T. Pfeffer

Gebremedhin, Mussie Gebregiorgis (M.S. Civil Engineering)

Applications of Augmented Reality in the Construction Industry

Thesis directed by Dr. Paul M. Goodrum

A big driver in the construction industry, like most others, is productivity. Naturally, everyone would like to get the maximum possible output, after providing the minimum possible input. With the growing age of technology, we are beginning to see more technology efforts aimed at being used as a tool for construction and construction related activities. A few examples of such technologies include the use of drones, GPS mapping, and virtual and augmented reality (VR & AR). This paper is an exploration of current and historical applications of augmented reality, specifically how these technologies have been used and are currently being used to display information. The goal is to learn more about some of the limitations and potential opportunities of using AR to display information. Furthermore, what effects does AR support have on user performance and behavior. We will begin this process by learning the definition and origin of AR and other related technologies. We will then look at how AR technologies have specifically been implemented in the construction and similar industries.

This paper also provides a tutorial on the development of an AR application. An AR application was developed for two reasons. One, to serve as proof of concept for our research team and second to explore how having access to an AR application affects a user's performance and behavior. The goal was to develop an application that could both display details and information that could be toggled on and off using virtual buttons, and also to generate a 3D model that could be viewed from any angle, allowing the user to understand the complete geometry of the 3D model. This exploration serves as the first of many endeavors the University's research team hopes to undertake in the field of virtual and augmented reality.

Contents

Tables

Figures

Chapter 1 – Augmented Reality

As a prelude to research efforts into this subject, a literature review was done to better understand the current level of industry sophistication when it comes to the use of technology such as AR. From the literature we were also able to learn more about what works now and what steps still need to be taken to better incorporate and use these technologies in various industries.

1.1 – Defining Augmented Reality

"Augmented Reality or "AR" is the result of using technology to superimpose or overlay information on the world we see (Emspak et al. 2018)." Basically, augmented reality is technology that is developed with the purpose of integrating the digital and real worlds. The overlay of information can include contents such as sounds, images, and even text. This is what separates "augmented" reality from what we know to be "virtual" reality. Rather than being completely immersed in the environment, one is only shown a view of added "augmentations" to their own environment, thus the term. Figure 1. below gives some illustration to the difference between the two technologies.

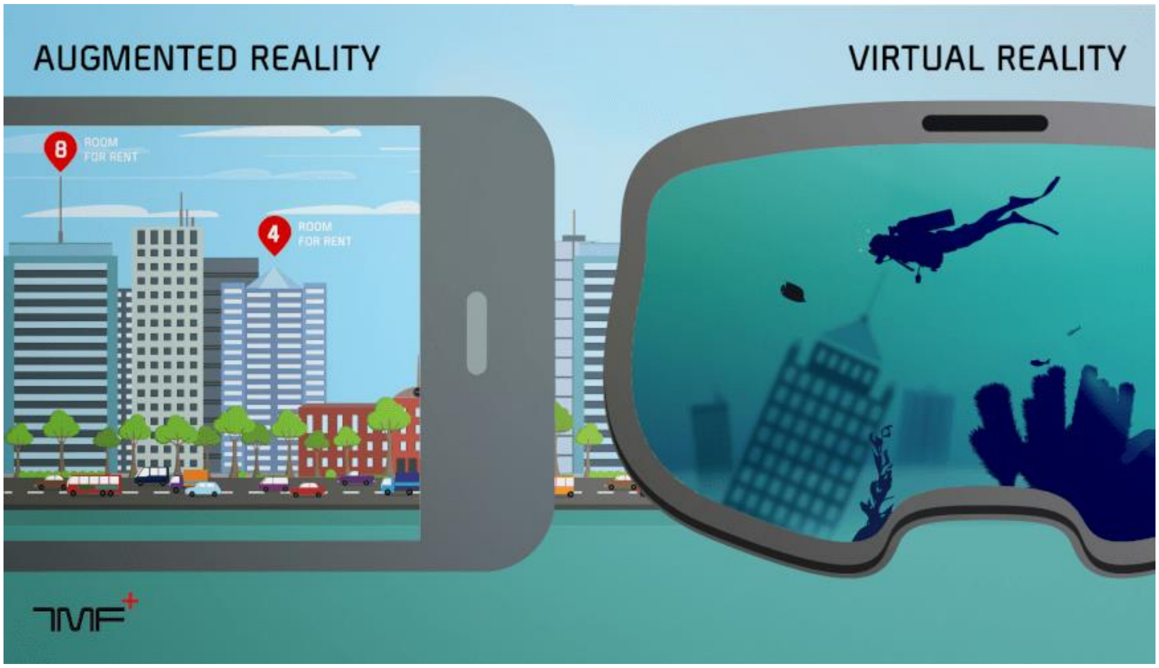

Figure 1. Augmented Reality Vs. Virtual Reality

To get a more likely familiar understanding of the difference between augmented and virtual reality one can refer to the popular phone application, “Pokémon GO”. This application uses augmented reality. The image below shows a screenshot from the application displaying how the developers used AR to overlay the characters and other details on the user’s world using the device’s camera.

Figure 2. In-Game screenshots of "Pokémon Go" showing use of AR Technology.

1.2 - How "AR" Systems Work

Technologies such as augmented reality were initially created and have since been further developed with the hopes of designing efficient technological advancements and adaptations in response to life's everyday challenges. To understand how AR technologies work, we can look at a simple smartphone. Say that the smartphone has some sort of location component (i.e. GPS), to locate the device/user at a place. "The smartphone then compares data from the camera to other data, usually image-based data, stored in a database. This allows the smartphone to know or to recognize what the camera is "looking" at. Sometimes, augmented reality systems get their cues from physical markers (think of something like quick response (QR) codes) that have been placed on objects in the environment (Berryman et al. 2012)." Figure 3. Illustrates what a physical marker or "image target" can look like.

Figure 3. QR code image target for augmented reality generation.

After this, the system pulls in data from web-based sources that would be overlaid on that picture. In the case of the above figure, the image target was activated to generate a basketball hoop model/game. The above is just one example, the truth is, data used in augmented reality can come from a multitude of sources. Data can be leveraged from well-known sources such as Google, Twitter, and Yelp, but data for AR can also be brought in from independent and completely different sources. The camera works by tracking information so the digitally displayed data must be done so in a way that is congruent with target tracking. When dealing with target tracking based technology, aspects such as angle and height must be taken into consideration. The overarching goal with how AR technologies work is to provide an individual or team with more information than the present reality can display. To best understand the current level of sophistication of AR technology within industries such as the construction and other fields, one must look to the origins and more sow the history of the development of the technology.

1.3 - History of Augmented Reality

Although the term AR was first coined in the year 1990, the concept of using augmented reality has a history that stretches back much further. The term “augmented reality” is considered to have been first introduced by two men, Tom Caudell and David Mizell. In 1990, Caudell was working for Boeing (a leading defense contractor). While working for the company Caudell “designed a head-mounted digital display … to help workers wiring aircraft by displaying a plane's schematics on the factory floor (Vaughan-Nichols, S.J. et al. 2009).” We also saw the use of AR to assist British military fighter pilots during World War II. During WWII, the British military was working on the development of “The Mark VIII Airborne Interception Radar Gun-sighting project”. “This project developed technology that displayed radar information on the windshield of a fighter plane and allowed the pilot to determine, among other things, whether or not the planes nearby were friend or foe (Vaughan-Nichols, S.J. et al. 2009).”

Another time that we saw early signs of AR usage was in the motion picture industry during the 1950s. A cinematographer named Morton Heilig, envisioned a movie experience for viewers that not only would engage their sight and sound, but somehow be able to incorporate aspects catering to all five senses. “In 1955, he wrote a paper describing his vision and in 1962 built Sensorama, a prototype of what he saw as an immersive experience of theater and the device received a patent (Berryman et al. 2012).” Because of this groundbreaking work, and the fact that his ideas, creations, and visions preceded the modern digital computing age, many see him and the work he produced as the forerunner for the development of today’s augmented reality. The figure below displays an advertisement for “Sensorama” from the 1960’s.

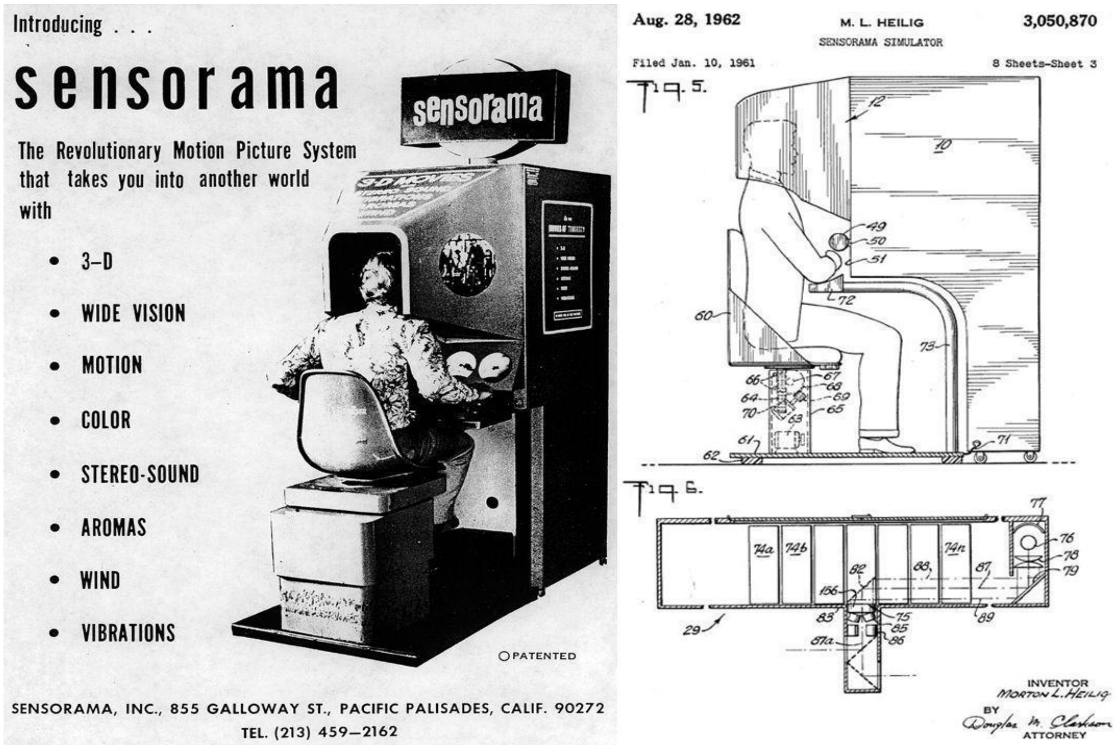

Figure 4. Advertisement for Sensorama motion picture system.

Shortly After, in 1966, a professor by the name of Ivan Sutherland created a head-mounted display that was invented with the purpose of merging computerized information with reality around us. “Two years later, in 1968, Sutherland, along with his graduate students, built what is recognized as the first augmented reality system, utilizing his head-mounted display. It was quite the contraption, with the head-mounted display connected to the large computers of that time as well as connections to the ceiling (it was a wired device) (Berryman et al. 2012).”

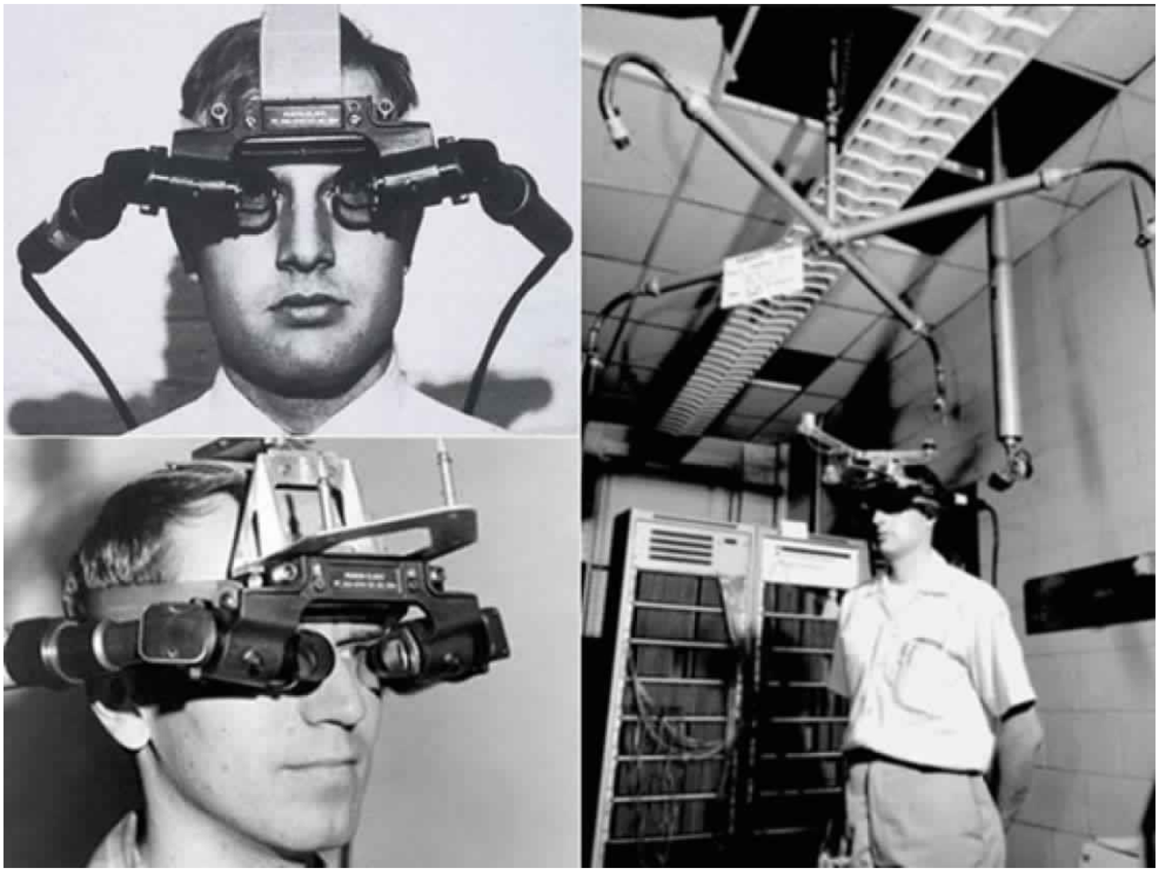

Figure 5. Ivan Sutherland's head-mounted 3D display technology.

By the mid 1970’s and spilling over into the 1980’s, AR began to build more recognition as a topic of interest. “The use of AR technology was then being studied in nationally recognized places such as the Armstrong Lab (U.S. Air Force), the Ames Research Center (National Aeronautics and Space Administration), and the University of North Carolina at Chapel Hill, among other places (Feiner et al 2002).”

In 1997, Ronald Azuma was credited with defining, more clearly, the concept of AR, noting that AR was defined as a combination between reality and computer-generated information. A few years later in 2000, Bruce Thomas built the first AR game, “ARQuake”. ARQuake is an augmented reality version of the popular first-person shooter game “Quake”.

ARQuake uses a head mounted display, mobile computer, head tracker, and a GPS system. This can be seen in the figure below.

Figure 6. ARQuake in game view and equipment.

By the late 2000s the use of AR in various industries was becoming increasingly common. In 2007, they began using augmented reality for medical applications. Similarly, industries such as media, gaming, entertainment and even the fashion sector were beginning to make use of such technologies. One of the more publicized developments was the Sixth Sense, which was shown to the world for the first time at a TED conference in 2009. Patti Maes and Pranav Mistry, from MIT, developed Sixth Sense, a wearable device that not only augments reality but also is able to turn almost any surface into a computer. Combining our digital lives with our current environment continues to be of interest to researchers and developers in a myriad of fields. The timeline below gives a broad overview of AR technology's progress leading to recent years.

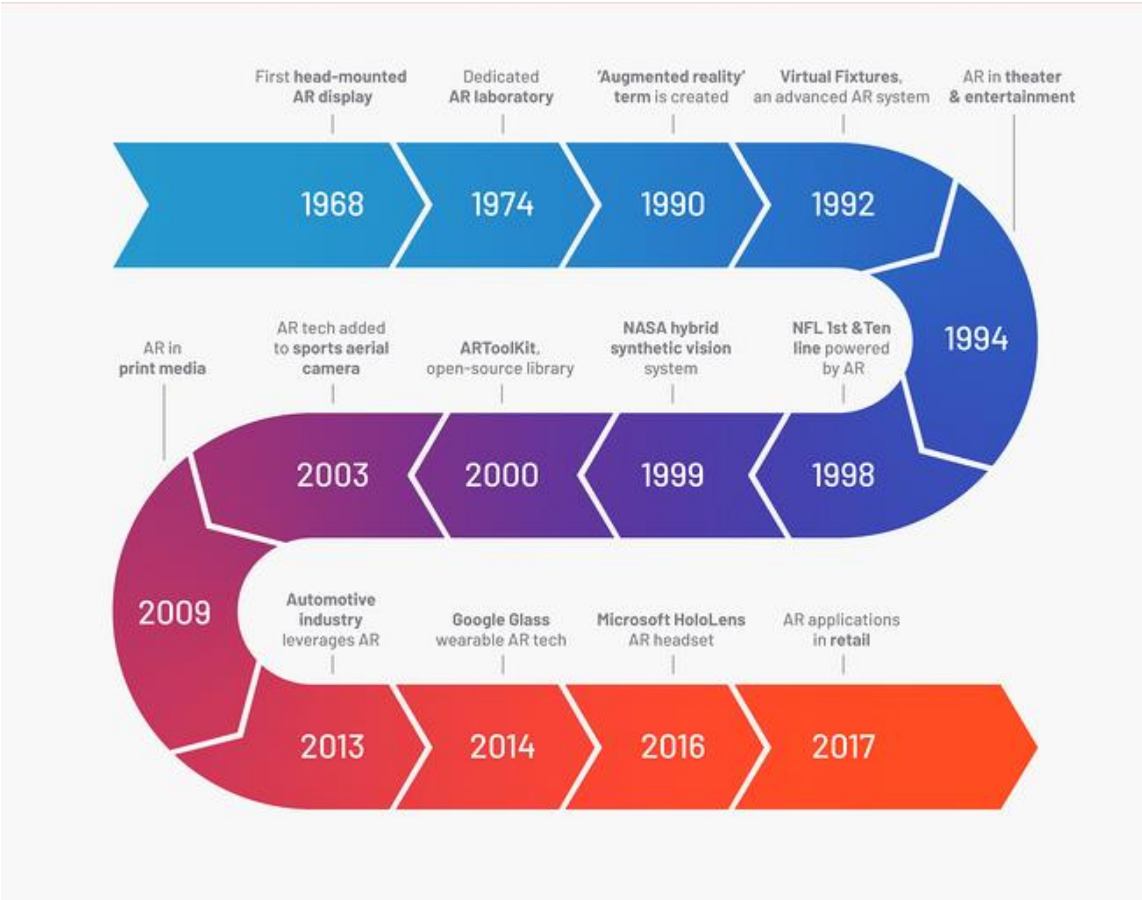

Figure 7. The History of Augmented Reality

1.4 – AR in the Construction Industry

The construction industry is not the first thought that comes to mind when one thinks of industry leaders in implementing new technologies. One of the reasons for this is how long the construction Industry has been around. "AEC (Architecture, Engineering, and Construction) sector has been out there longer than many other industries on our planet. That is one of the reasons why new technologies are implemented slower than in other domains." (Morozova et al.

2019). Also, in the construction industry most budgets for Research and Development (R&D) are typically smaller than those of other Industries.

To combat the tradition of slow technology implementation and integration, many in the sector have looked to applications of augmented reality for a boost. In the last few years, the construction industry has begun experimenting with the use of AR wearables and mobile devices.

1.4.1 Overlaying BIM Models

One way that the construction industry has begun implementing AR us has been with "AR Wearables" such as the "HoloLens" which is used to superimpose BIM Models over the real world. "By using a headset (like HoloLens), a contractor or manager can walk inside a BIM model overlaid on the real world. By doing so, they can compare what has been planned with what has been build and evaluate the work on the spot (Morozova et al. 2019)." This technology can also be used during the project planning process to allow designers and clients to preview the buildings and can make changes before construction. These innovations to avoid costly changes and keep clients engaged over the course a project.

1.4.2 Field Measurements

AR technology is also being used in the construction industry to perform automated measurements. Augmented reality technology has the capacity to measure a space's height, width, and depth allowing the user to have a better understanding of a space's physical properties. "Construction companies can incorporate this data into models, allowing them to generate even more accurate structures and have a more comprehensive view of how the project will look like (Stannard 2019)." Using AR for field measurements can assist with project schedule efficiency and anticipation of material needs.

1.4.3 Safety and Training

One of the biggest challenges that continues to face the construction industry is safety. Wearables like DAQRI smart glasses and the HoloLens are currently being used by as safety equipment for inspection. Traditionally, the inspection process is done manually requiring multiple individuals to complete. With these technologies, Inspectors can accurately compare the as-built vs the BIM model.

In the construction industry, heavy machinery is a key requirement for the building process. These machines require hours of training and in recent years, construction companies have been using AR headsets that give users the ability to perform tasks while being given instructions in real time. This technology drastically reduces training costs and downtime. Additionally, augmented reality can provide a safer training environment because staff can work with large machinery with reduced risk of injury (Chinn 2019)."

1.5 Limitations of Augmented Reality

One of the primary limitations of the implementation of augmented reality and other related technologies are concerns around the complexity of the services. For instance, there is no standards for AR, this means that interoperability is not possible with the current level of sophistication. This requires every device and platform to have a unique/individual development.

Furthermore, the location-based services that are being used currently in devices such as smartphones does not have the capacity for locating to the degree of accuracy that is needed for augmented reality integration. This is supplemented with other challenges with devices such as smartphones, i.e. device signals may be interrupted or blocked by buildings and using devices indoors. Beyond the technological shortcomings, there are also complex issues facing augmented reality such as privacy issues, ethical issues, and other user issues related to the varying levels of intuitive technologies. Despite these limitations it is evident that the use of AR has been able to contribute towards improvements in various industries.

Chapter 2 – AR Application “Prototype Development”

To further explore the potential impacts, if any, that AR provided information has on individual, an augmented reality application was developed. This application would serve as a proof of concept displaying how one can develop an AR application that allows a user to toggle different pieces of information for a pipe assembly using virtual buttons. This application was also developed to learn more about how having access to different amounts of information can influence a subject’s behavior and performance when completing an assembly.

The process of creating this app was challenging. The task required an iterative process for learning to code and build software to different devices and platforms. The next section will take you through a tutorial for the process of creating the application. The purpose of this tutorial is to allow the application to be replicated for future research efforts.

2.1– Software Downloads

This tutorial was made using a pc and the application will be built for android device settings. Some steps may need to be augmented or amended if one intends to build to iOS or another VR/AR platform. To complete this tutorial, you must download the latest version of the Unity engine and Virtual Studio.

The Unity download should include both android build support and universal windows platform build support. These build supports are particular to the tutorial, but you can apply this same logic to whatever platform you choose to build your application to. For example, if you are planning on building this application for an IOS/Apple device, you would download Unity with the IOS build support. If you do not download these items initially, or if you decide later you want to build to other operating systems, you can go within Unity and update and re-download the software to include your desired build capabilities.

2.2 Creating a Project

After successfully downloading all the above software, follow the below instructions to begin creating a new Unity project. Open the unity application → Create a Unity account → Login to your Unity account → Create a new project. Choose a project name and select a location for the project. Ensure the "3D Template" is selected.

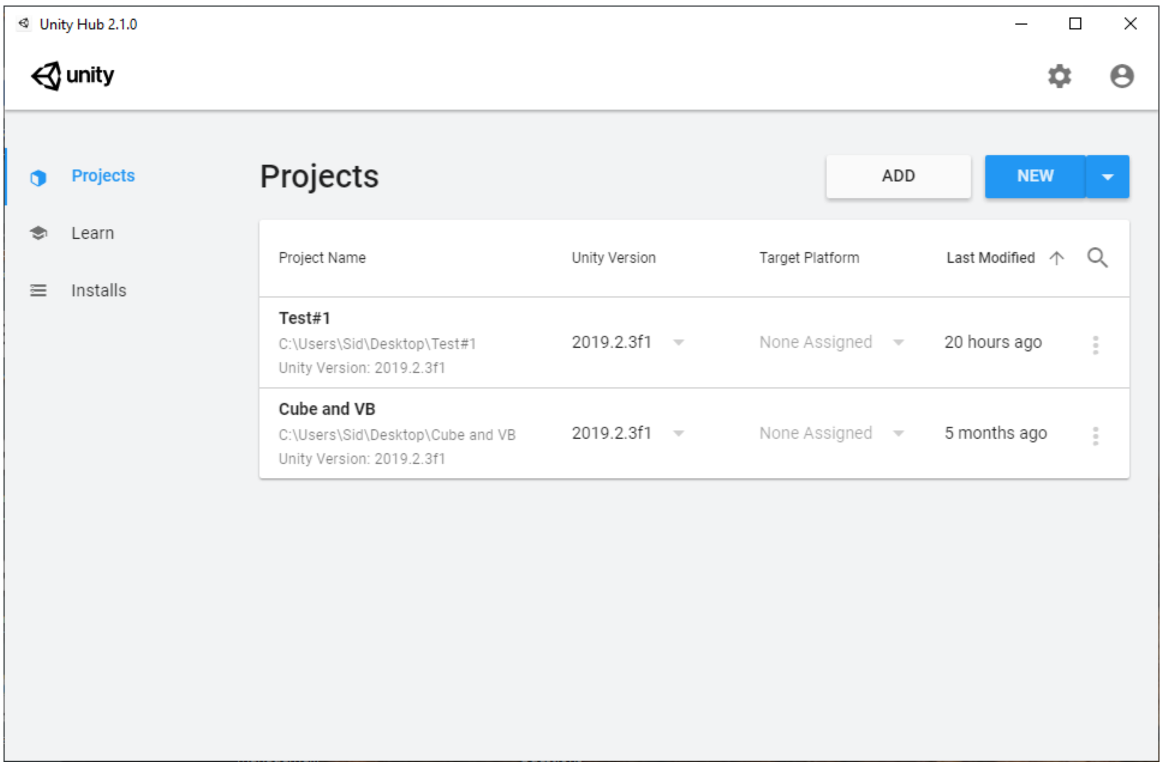

Figure 8. Unity Project Window

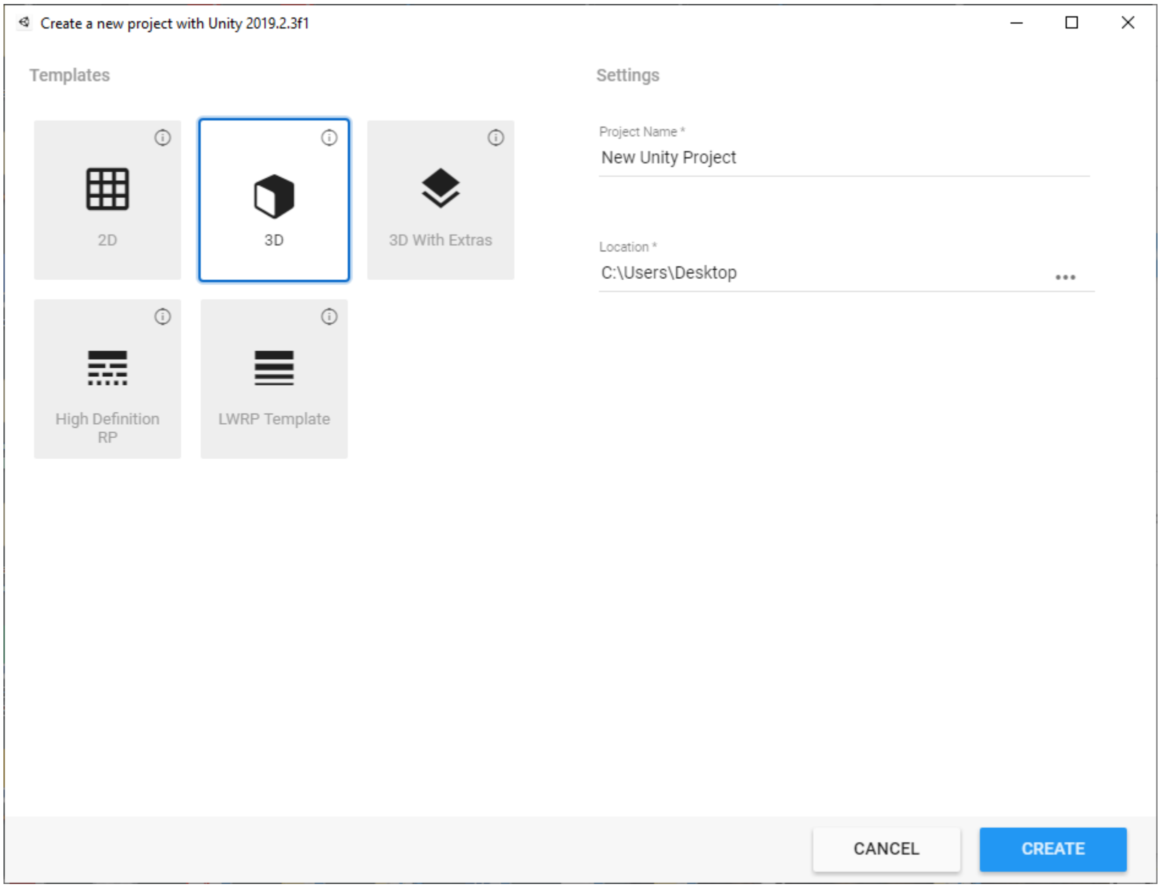

Figure 9. Unity Templates Selection Window

2.2.1 Enabling the Vuforia SDK

Edit Menu → Project Settings → Player → XR Settings → click the check box next to "Vuforia Augmented Reality Supported".

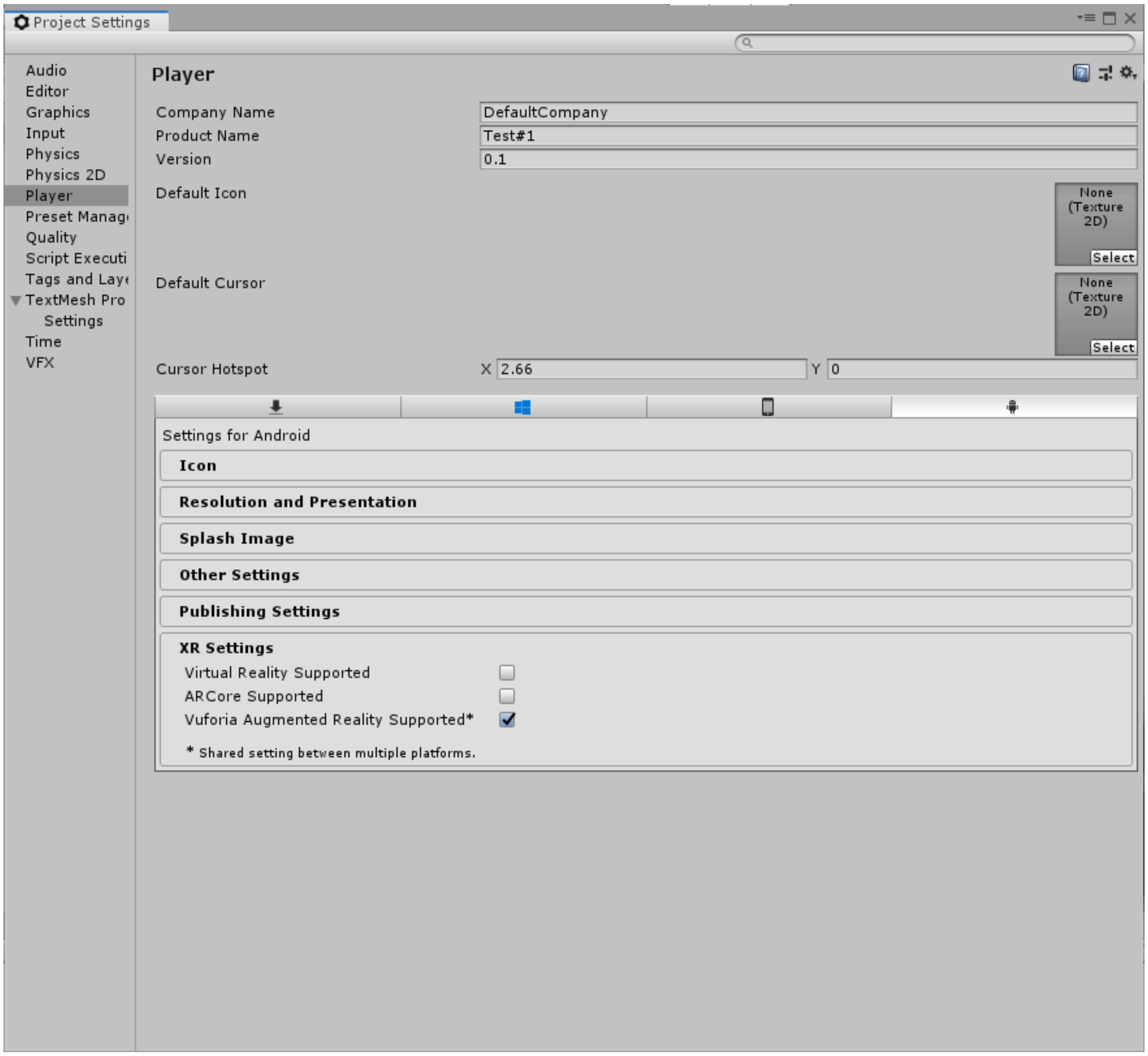

Figure 10. Player Settings Window used to enable Vuforia Engine.

2.2.2 Identification

Next, the user will need to create a unique identification package name for the application. To do this, navigate to the "other settings" tab located on the same window. You are then going to change the "Identification Package Name" to a unique label. Remember, you must use the following format within Unity "com.xxx.xxx". The "xxx's" can be replaced by the user's unique input. There are also IOS and universal windows platform tabs. This process will need to be repeated for any platform you intend to build to. See Figure 11. below, the application Package name chosen was "UniversityofColorado.Test1".

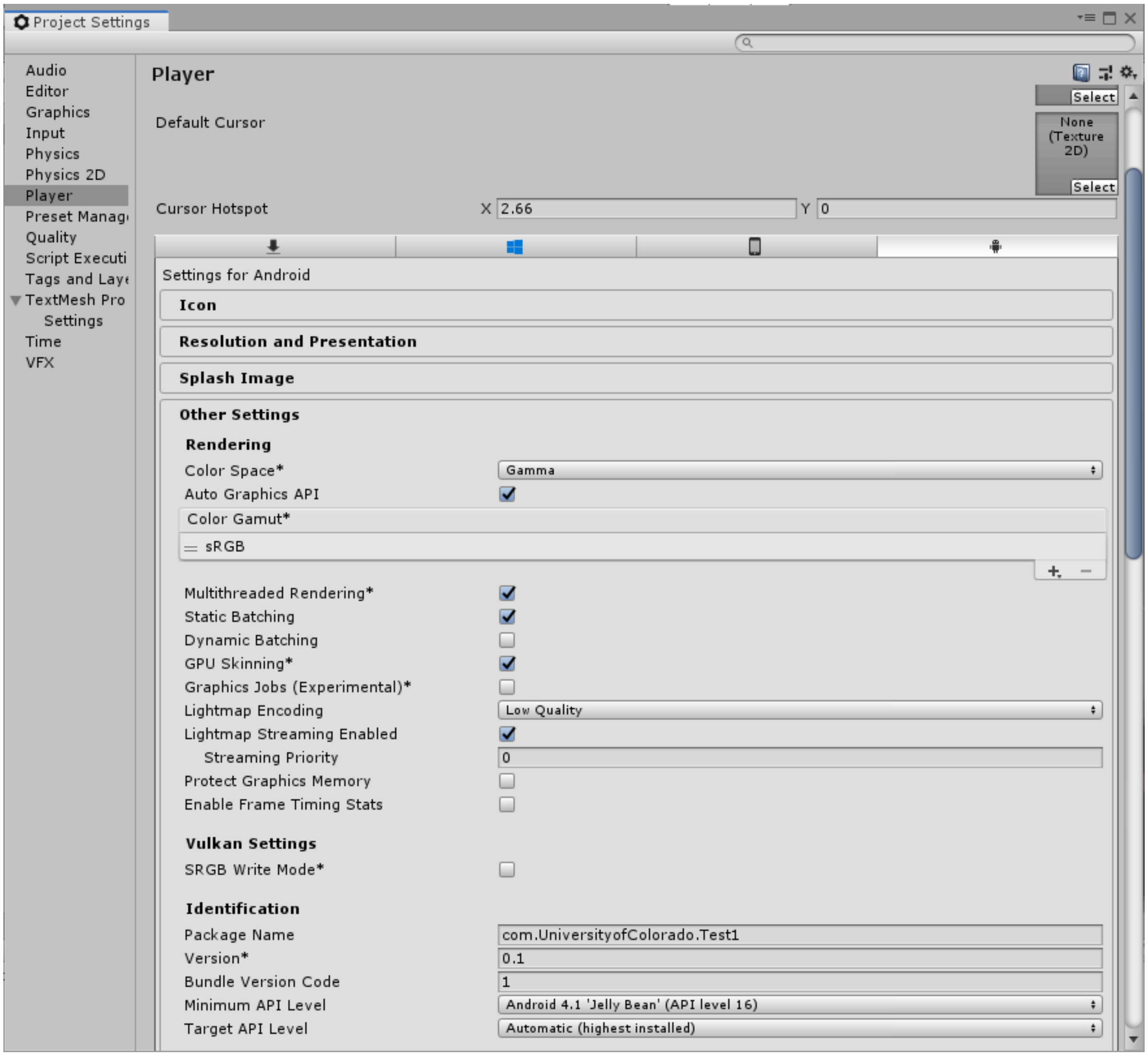

Figure 11. "Other Settings" Window used to change Identification Package name.

2.2.3 Hierarchy Window

You can now exit the “Project Window”. You should then see the screen below in Figure 12., this is the home screen for your Unity project. The home screen displays component hierarchy to the left, an inspector window to the right, and project and console tabs on the bottom. The hierarchy window works as an outline for the application, it does so by displaying all components you incorporate into your project scene.

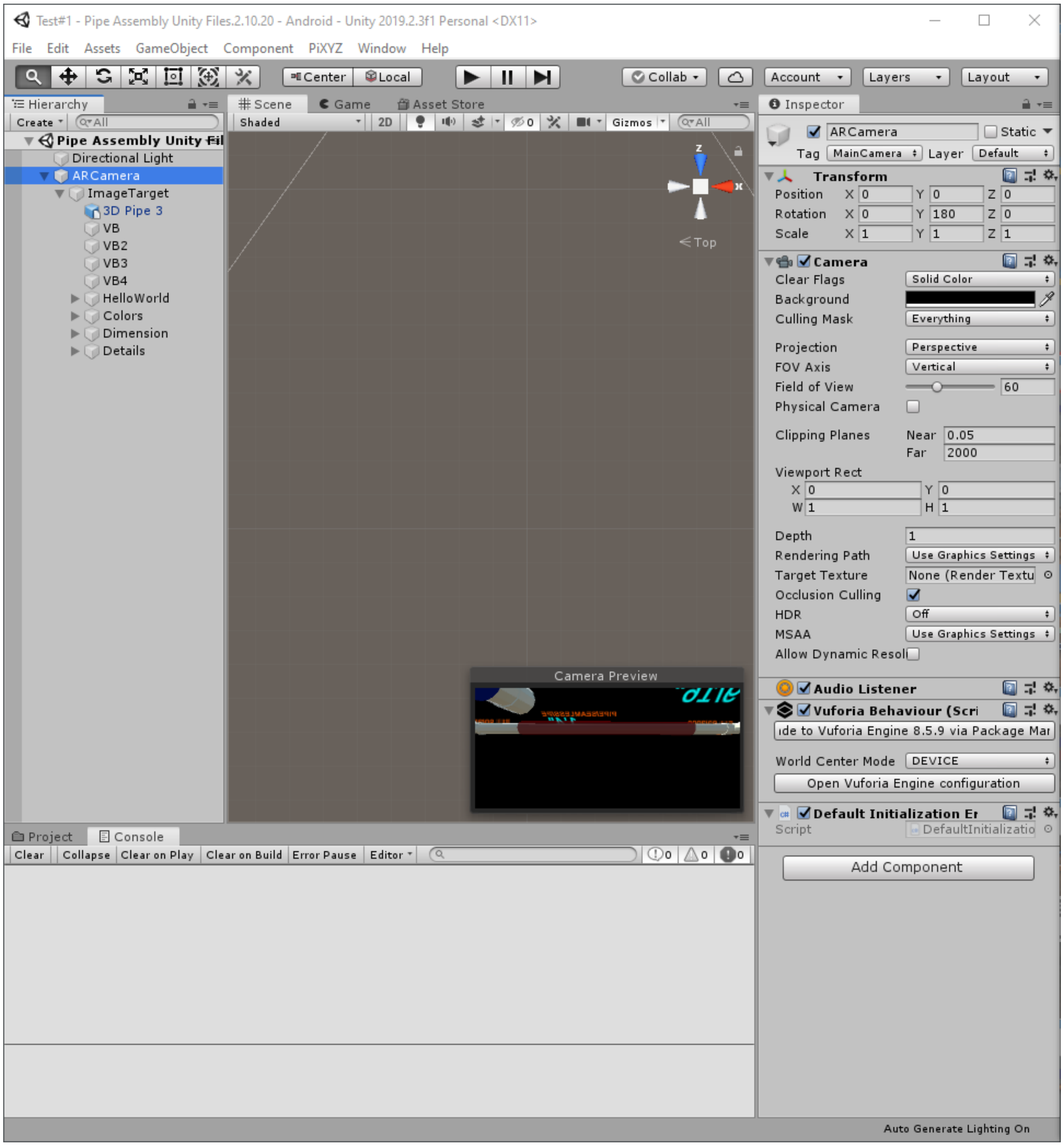

Figure 12. Unity "Home Screen".

2.2.4 Vuforia Camera

To add the Vuforia Camera to the scene, right click on the above shown Hierarchy tab. You will first need to delete the main camera, which is automatically added when you create a new project in Unity. Replace this camera with the Vuforia AR camera.

2.2.5 Vuforia Engine Configuration and License Key

On the left side of the screen you should see the “Inspector Window”. From the inspector window. You will then need to navigate to and access the Vuforia engine configuration. This is located under the dropdown of the Vuforia Behavior (Script) tab located towards the bottom of the Inspector window. Once you open the Vuforia engine configuration, select add license. Your screen should look like Figure 13 below.

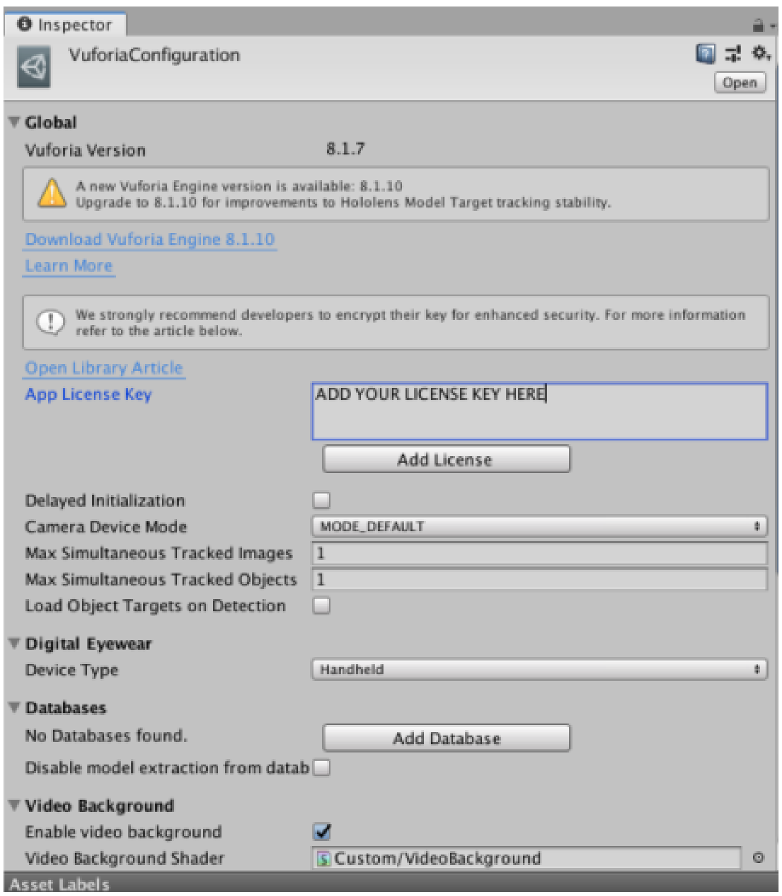

Figure 13. Vuforia engine configuration window.

Selecting add license will then launch the Vuforia Developer page. You must create an account and log in. Once you have logged in Vuforia will let you generate a unique license key. Copy the generated license key to “App License Key” box in Unity.

2.3 Uploading Image Target

We will need to define and upload an image target for our AR camera to identify and subsequently generate the project and project objects you create in Unity. You must first select a unique image target for your project. What image or pattern you select as your image target is your choice? For this tutorial/experiment we went with an image including our University's logo. You can see our image target below in Figure 14.

Figure 14. University of Colorado Logo image target.

Once you have made an image target selection open the Vuforia Developer website and follow the steps below.

Image Target → Add Database → Device. You will then be asked to name the project. See Figure 15. Below for reference.

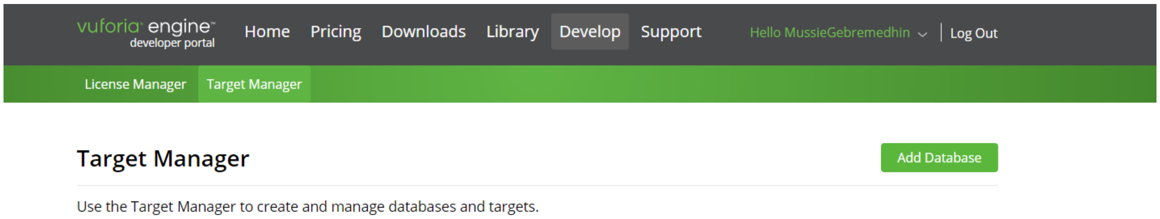

Figure 15. Vuforia Developer Portal website screenshot.

From there you will then follow these steps. Add Target → Select the Single Image Type → Upload your selected image target file → enter an image target width (You can enter 5 for default Width). You can then give the image target a unique and select add.

2.3.1 Creating Database

Next you will download the database that was just created. When downloading select the Unity Editor file type. This will allow you to open the image target file in Unity. To import the image target you must save the file to the assets folder within Unity. You can drag the file and drop it into the asset folder located at the bottom of the Unity window alongside the Console tab. See Figure 16. Below for reference.

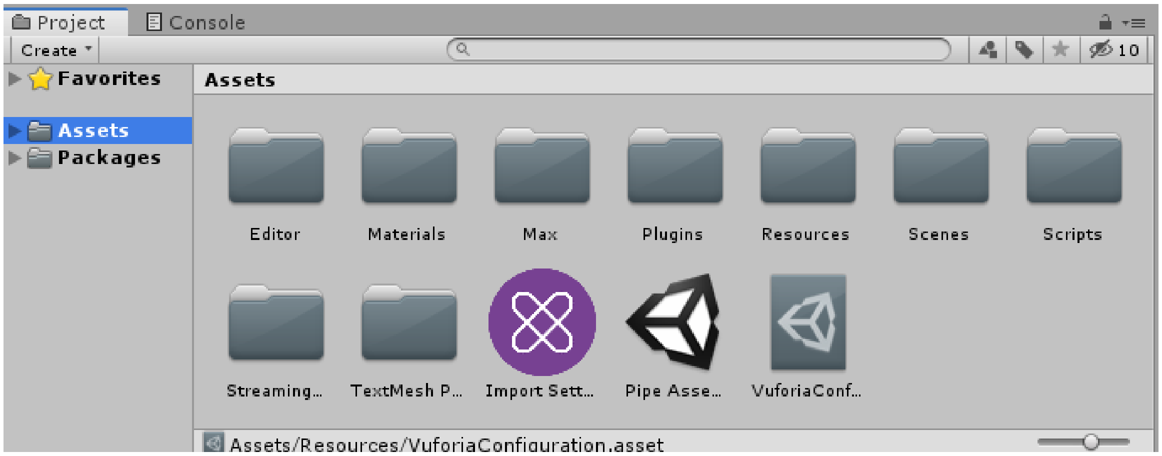

Figure 16. "Assets" folder located in Project window of Unity.

2.3.2 Adding Image Target to Scene

To add an image target to your project scene you can follow these steps. → Open Vuforia engine configuration → Databases → Select your previously defined image target

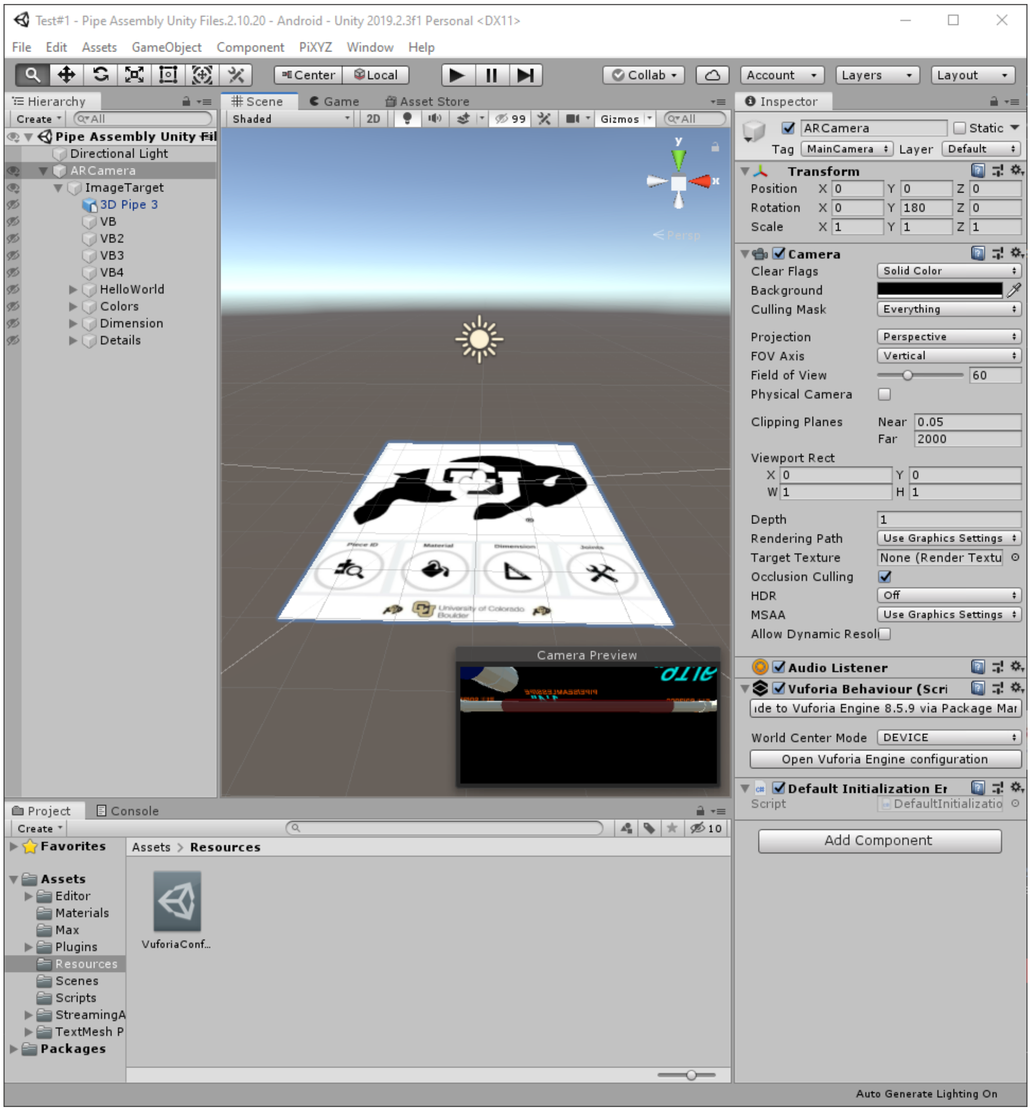

Figure 17. Image Target uploaded to Unity scene.

2.4 Adding Objects

Generally, you can add objects by right-clicking on the Hierarchy window and then selecting a 3D object, 2D object etc. For this tutorial we wanted our object to be the piping model which we had on file as a dwg (AutoCAD) format. Unity cannot read dwg files so you must convert the file from a dwg into a file type that Unity can support, i.e. a “3Dsmax” file type. You can import your dwg file into the AutoCAD program 3ds Max 2020. From here you can then export the file out of the program as a 3dsmax file type, which unity will accept.

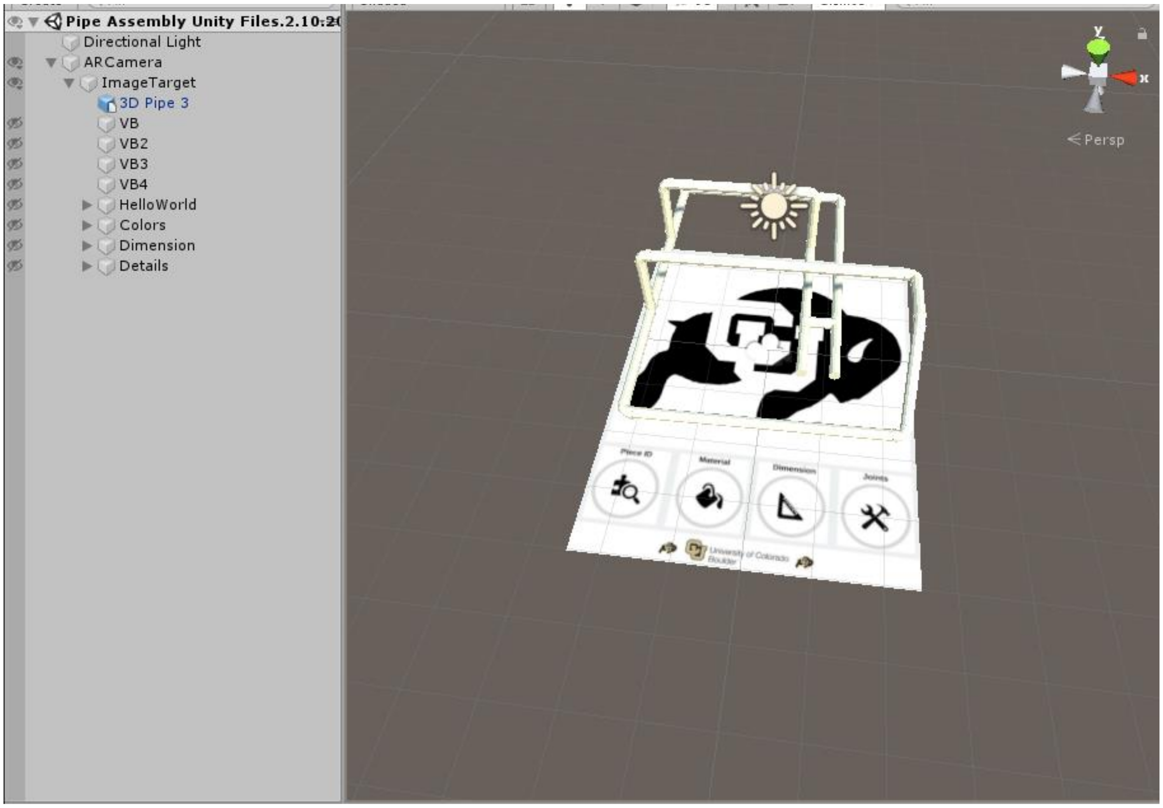

Figure 18. 3D Piping model imported as a 3dsmax file type.

2.4.1 Overlay Objects

Before we can add Virtual Buttons, we must first add objects that display information to the Unity scene. To do this right click on the hierarchy window to the left → 3D Object. From here you can select cylinder, plane, cube, etc. To add text overlay to the piping model you can select either “3D Text” or “TextMeshPro”. The difference between these two is mostly aesthetic. Figure 19. Below illustrates how an object can be added to a Unity scene. For our piping model we had four different object groups overlaying information that would be triggered by separate virtual buttons: HelloWorld, Colors, Dimensions and Details.

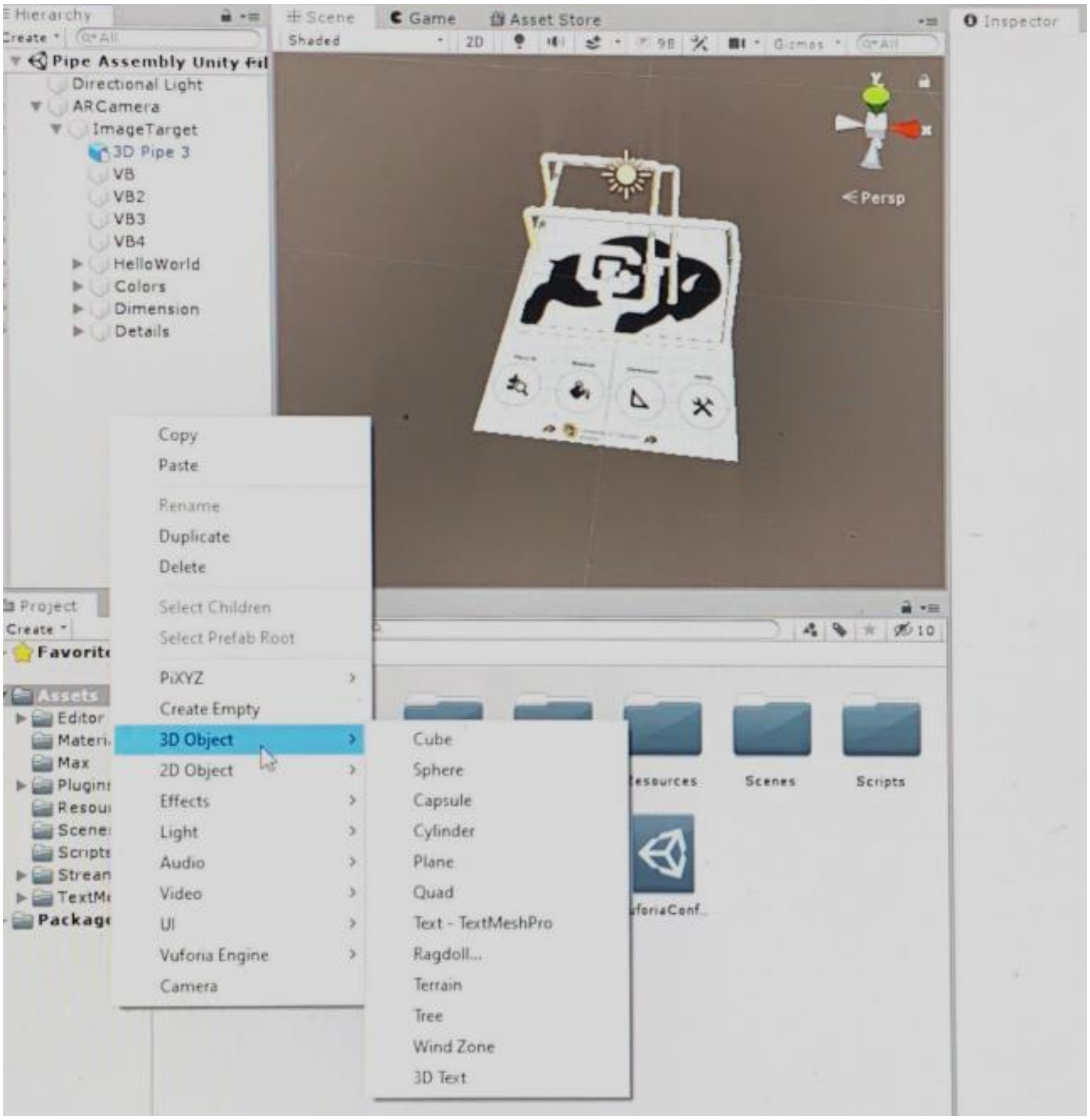

Figure 19. Screenshot illustrating how to add 3D objects to Unity scene

"HelloWorld" → Displays a 2D text showing the piece ID of each pipe of the model. See figure 20. Below showing the black text overlay named the "HelloWorld" object.

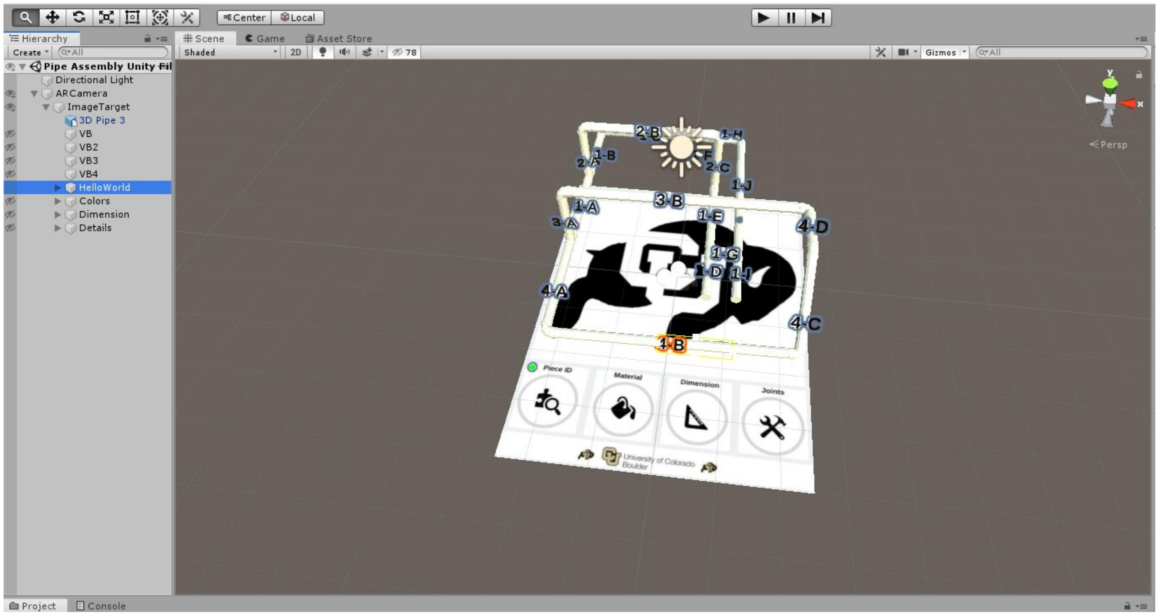

Figure 20. "HelloWorld" object overlaying pipe piece ID.

“Colors” → Displays the color identification overlay on the piping model. The objects for this overlay were made using the “Cylinder” option on the 3D objects menu mentioned above. Figure 21. Below illustrates the “Colors” object overlay.

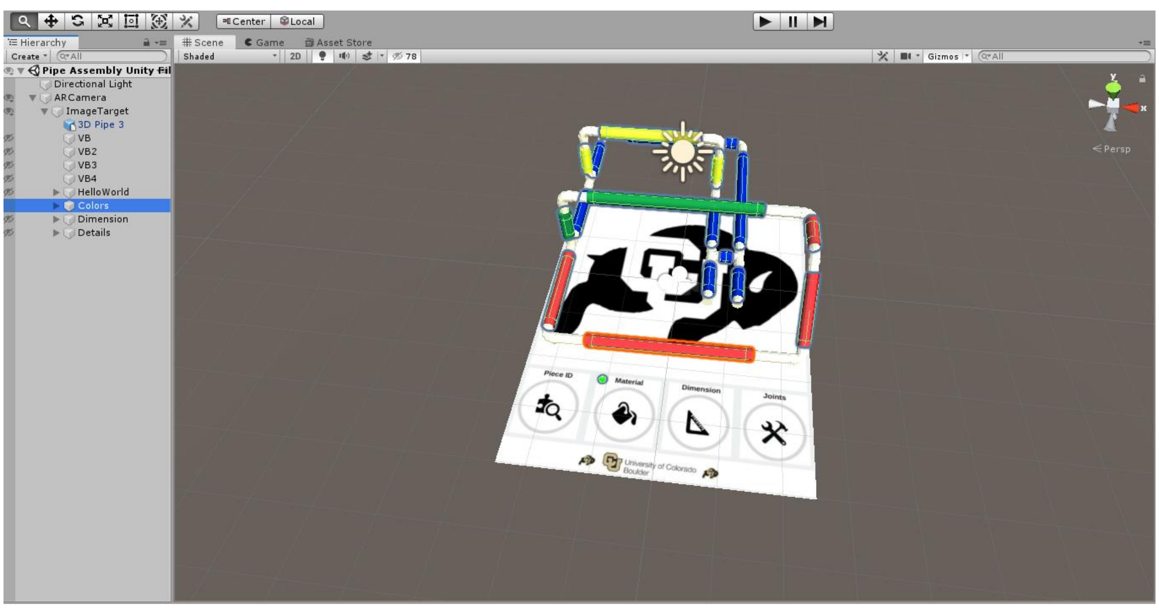

Figure 21. "Colors" object overlay indicating pipe color.

“Dimensions” → Displays an overlay providing the dimensions for each pipe in the pipe assembly. The dimensions display was created using the TextMeshPro object. The TextMeshPro object was also used for the “HelloWorld” display mentioned previously.

“Details” → Displays information regarding the joints needed to connect the entire piping model. Specifically, the Details overlay specifies to what degree the joint is bent, i.e. 45 degrees or 90 degrees. This display was also created using the TextMeshPro object. Figure 22. below illustrate both the “Dimensions” (light-blue) and the “Details” (orange) overlays on the piping assembly.

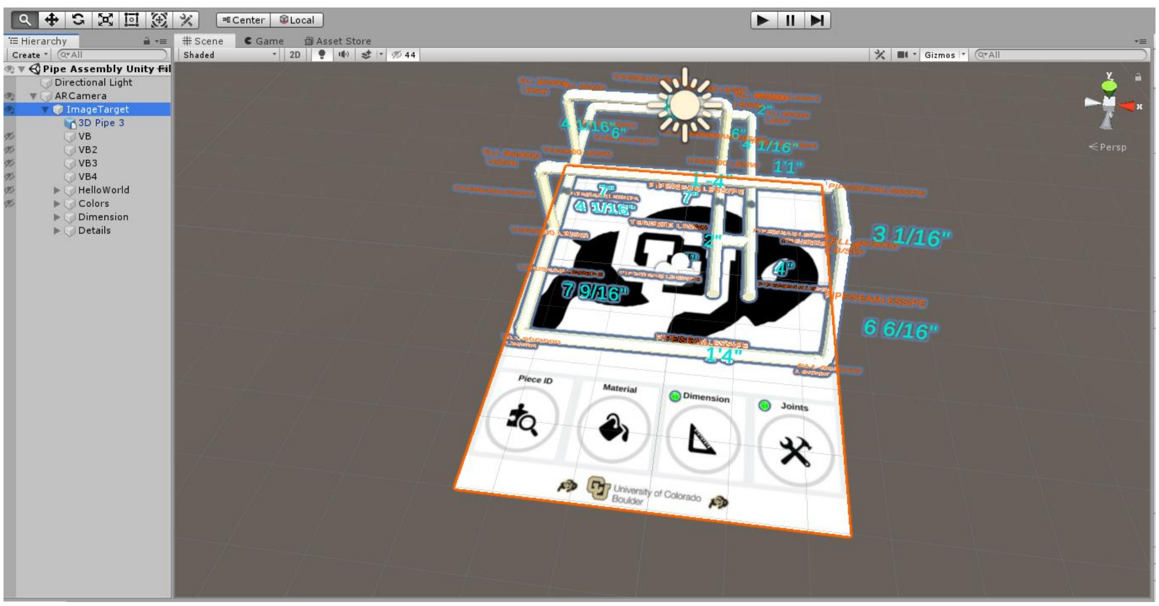

Figure 22. "Dimensions" (light blue) & "Details"(Orange) overlays on piping model.

Adding these overlays is time-consuming, this is because you will need to create a sub-object or child object for each piece of information within the above four overlays. This is a repetitive process but is needed to trigger groups of overlaid information while only using four buttons. Figure 23. below Illustrates this perfectly. In the Hierarchy window you will notice for example that under the object title “Colors”, I have individual objects for each color overlay on the piping model. For example, "Colors (1)" is the object giving the red overlay color to the diagonal pipe selected on the right side of the piping model.

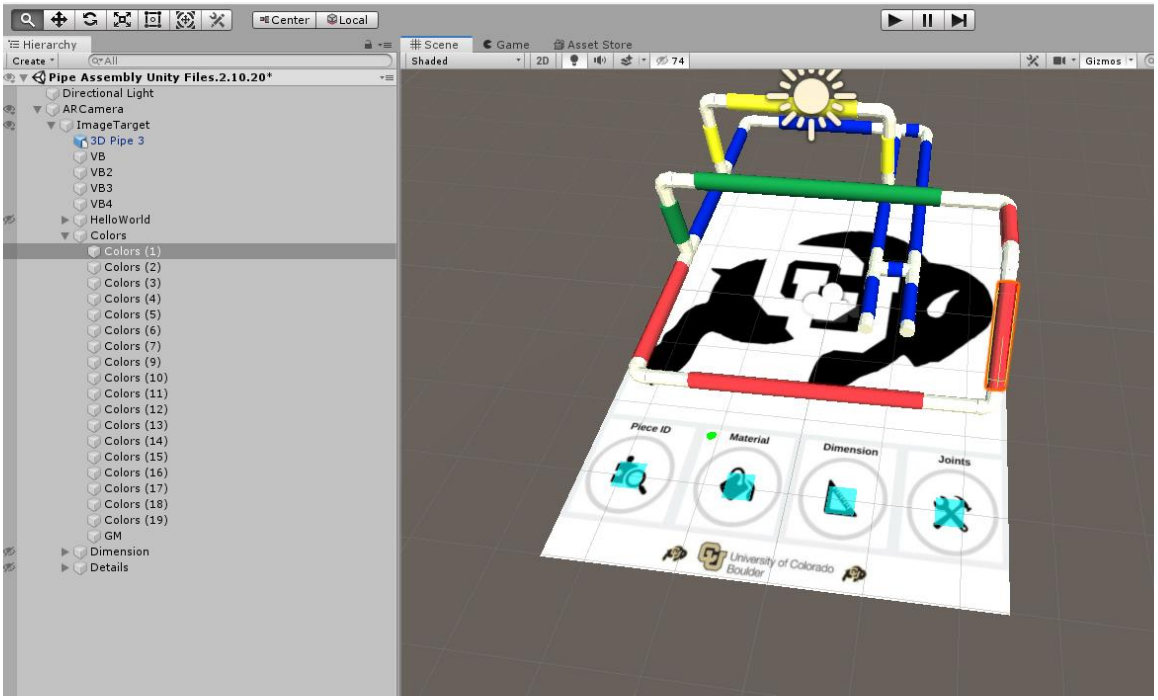

Figure 23. Screenshot illustrating the iterative nature of adding overlays.

2.5 Virtual Buttons

After you have successfully added in all your desired objects you will then need to add one or more "Virtual Button(s)". The purpose of virtual buttons is to invoke interactivity between your image targets moving on screen and the real world. These buttons serve as a powerful mechanism for making these image-based targets interactive. To add a virtual button, follow the steps below.

First, make sure the "Image Target" is selected in the hierarchy window. Next, navigate to the right side of screen, in the inspector window, then expand-down the "Advanced" tab under the "Image Target Behavior" section → select "Add Virtual Button". As you add virtual buttons, they will appear on the image target as teal colored squares which you can resize and relocate to wherever you desire on the image target. Figure 24. below illustrate the four virtual buttons used to create the piping model. The virtual buttons VB, VB2, VB3, VB4 will each be used to trigger the four unique objects/overlays we discussed above.

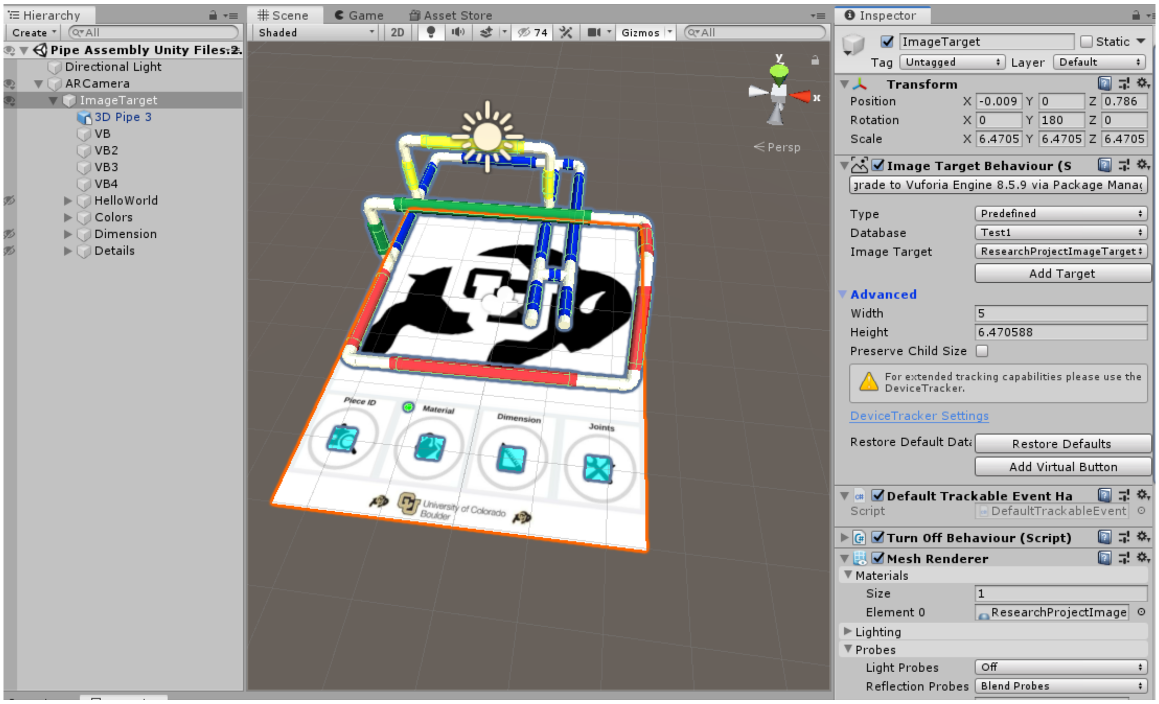

Figure 24. "Virtual Buttons" appear as teil colored tiles on image target.

2.5.1 Coding the Virtual Buttons

For the virtual buttons to work properly you must give them directions or a “code” to follow. This code can be written as a “script” in “Microsoft Visual Studios”. The piping assembly has four virtual buttons and four unique overlays of information, for this reason we will need to write four unique scripts of code for unity to build this application. To add a script, select one of the virtual buttons → navigate to the inspector window → select Add Component→new script. Name the new script and Unity should then open Visual Studios. Figure 25. below illustrated the first script “test script” on Visual Studios.

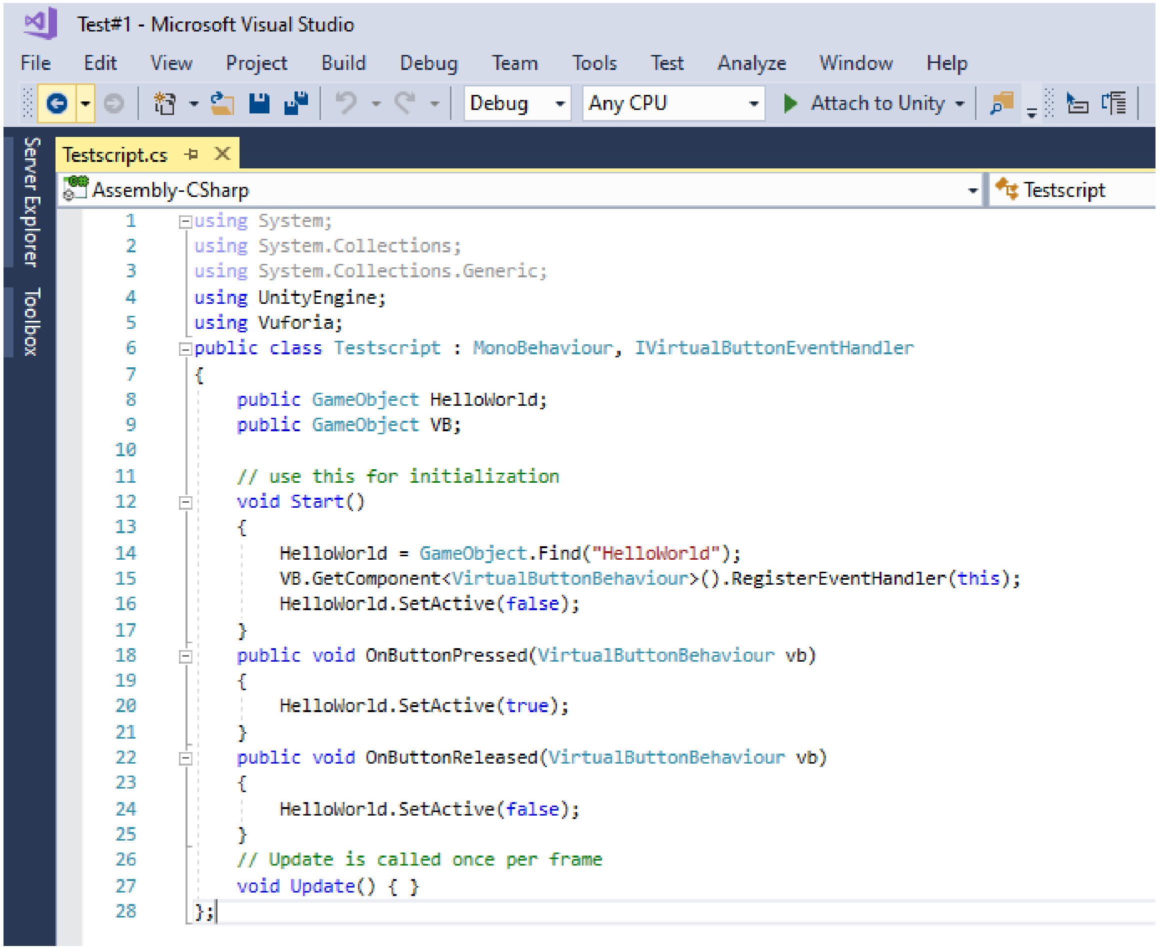

Figure 25. "Test script" using the "HelloWorld" and "VB" game objects.

The script above uses the “HelloWorld” and “VB” game objects, you will need to write a code script for the other three information overlays and virtual buttons. You can copy and paste the code from below. To apply this script to the other overlays and virtual buttons, simply replace any occurrences of HelloWorld/VB in the script with the appropriate pair. The below script “testscript2” is identical to the above, the only difference being the use of “Colors” and “VB2”.

```
using System;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using Vuforia;
public class Testscript2 : MonoBehaviour, IVirtualButtonEventHandler
{
public GameObject Colors;
public GameObject VB2;

// use this for initialization
void Start()
{
Colors = GameObject.Find("Colors");
VB2.GetComponent<VirtualButtonBehaviour>().RegisterEventHandler(this);
Colors.SetActive(false);
}
public void OnButtonPressed(VirtualButtonBehaviour vb)
{
Colors.SetActive(true);
}
public void OnButtonReleased(VirtualButtonBehaviour vb)
{
Colors.SetActive(false);
}
// Update is called once per frame
void Update() { }
};
```

2.5.3 Building Application to Device

Now that all the steps needed to create the application have been completed. The application can now be built to any AR compatible device. For the pipe assembly experiment an android build was used to upload the application to an android smart phone device. You must have your device plugged in via usb to the computer running the Unity application. You also may need to go into your devices setting to change the usb mode from charging mode to developer mode. The final steps are as follows.

File→ "Build Settings→ Platform (Android)→ "Build and Run". Once the program completes the transfer, you can access the application on your phone and test the results. See Figure 26. Below for reference.

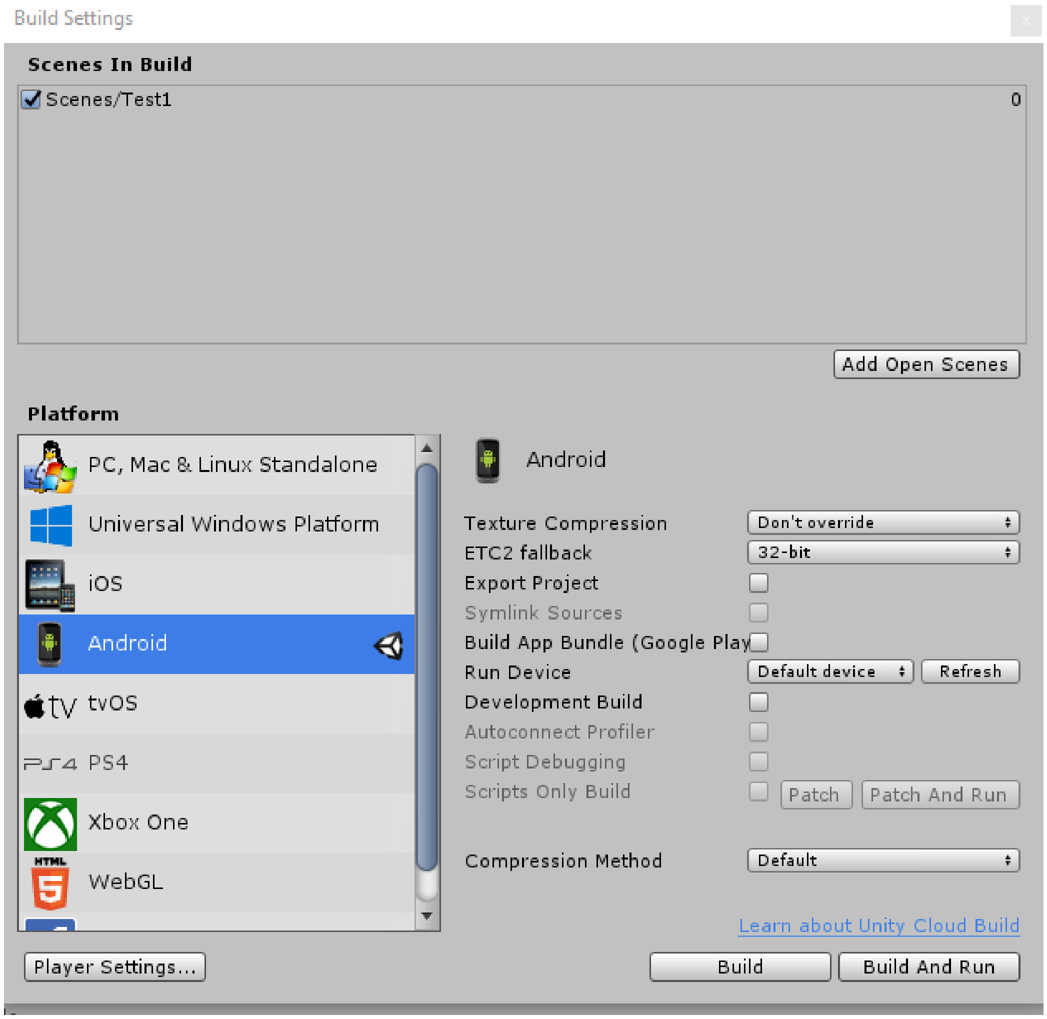

Figure 26. "Build Settings" window used to download application to AR compatible device.

Chapter 3 – Pipe Assembly Experiment

3.1 – Background

An experiment was conducted to explore how an application would perform under continued use by different participants and to begin to understand if access to the application would have an influence on performance and error recognition. The results of this experiment are intended to further assist our academic and industrial exploration of how access to differing amounts of information affects behavior and performance in subjects.

Students from the Psychology and the Civil engineering department were asked to serve as our subject pool. We asked the subjects to properly complete a partially begun piping model in as little time as possible. The sample population had a total of fifty-seven participants. The average age amongst participants was between 19-20 years old. However, the oldest participant was 57 years old.

We first had our participants come into the testing space which was divided into two rooms. The first room would be where they filled out a questionnaire asking them about their demographic identification and to give us a better gauge of the level of construction or construction-related experience they may have had. Once participants completed this portion, they were then called into our second room where the experiment would be conducted. In this room we directed participants to a table where they would be asked to complete a timed special cognition test.

3.2 - Spatial Cognition Tests

Regardless of the medium given to the subjects, it is important that they fully comprehend the task they are being asked to complete. This is where finite cognitive ability to process information is key. When workers, or in our case subjects interpret engineering information, such as on a set of drawings, they are making use of their special abilities, their understanding of spatial orientation. Spatial orientation is the ability to, "perceive spatial patterns or to maintain orientation with respect to objects in space (Ekstrom et al. 1976)."

The best way to describe this is simply an individual's ability to see information and then create and even manipulate the images of this information. "The steps to do so are encoding, remembering, transforming, and matching spatial information (Lohman et al. 1979)." Mentally reassembling orthographic displays leads to ambiguities, omissions, and interferences (Rieber et al. 1995)." The Educational Testing Service (ETS) has established two tests to evaluate a person's spatial relations ability, the card rotation test and cube comparison test (Ekstrom et al.1976)."

The card rotation test is used to measure one's ability to mentally manipulate two dimensional objects. Each card shape illustrates a 2D image with the choices being eight similar objects. Subjects are then asked to determine whether each object has only been rotated ("same") or if it has been both flipped and rotated ("different"). Figure 4 below displays a typical section from card rotation test.

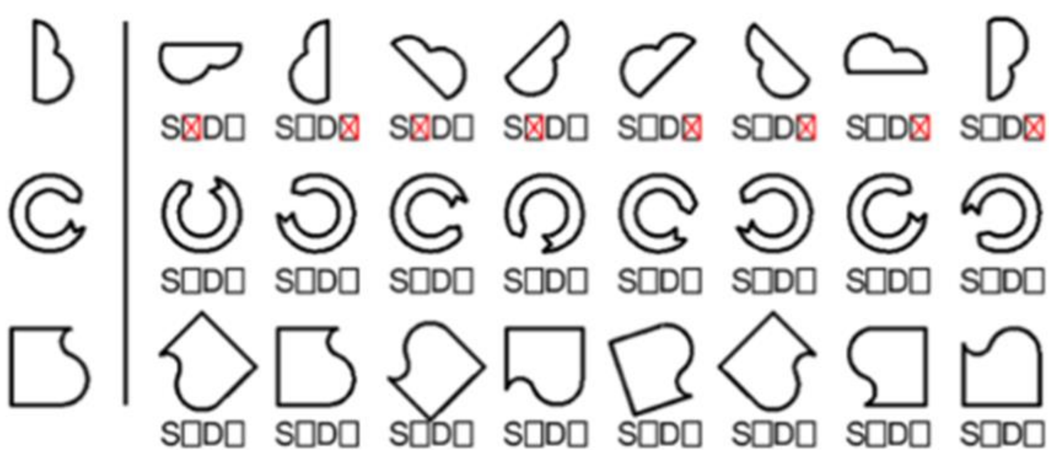

Figure 27. "Card Rotation" test questions.

The cube comparison test which was also used during this experiment is used to test an individual's three-dimensional cognitive abilities. In this case, typical questions depict two cubes marked with a letter on each face. If the first cube can be flipped and still resemble the second cube, the subject would then mark this as "same". If the cube cannot be turned to create a similar cube (due to incorrect relative position of letters), the subject would then mark this as "different". See Figure 5. Below of a typical question from the cube comparison test.

Figure 28." Cube Comparison" test questions.

After completing both spatial cognition test. Participants were then directed to the final/experiment table. At this point participants were asked to read the prompt outlining a story explaining that they were being asked to complete a partially completed pipe model given specific guidelines. The pipe model also had a purposefully introduced error. This error was a discrepancy between one of the pipes on the partially completed model and the information you were provided to complete the task. Figure 29. Below illustrates a properly completed piping assembly.

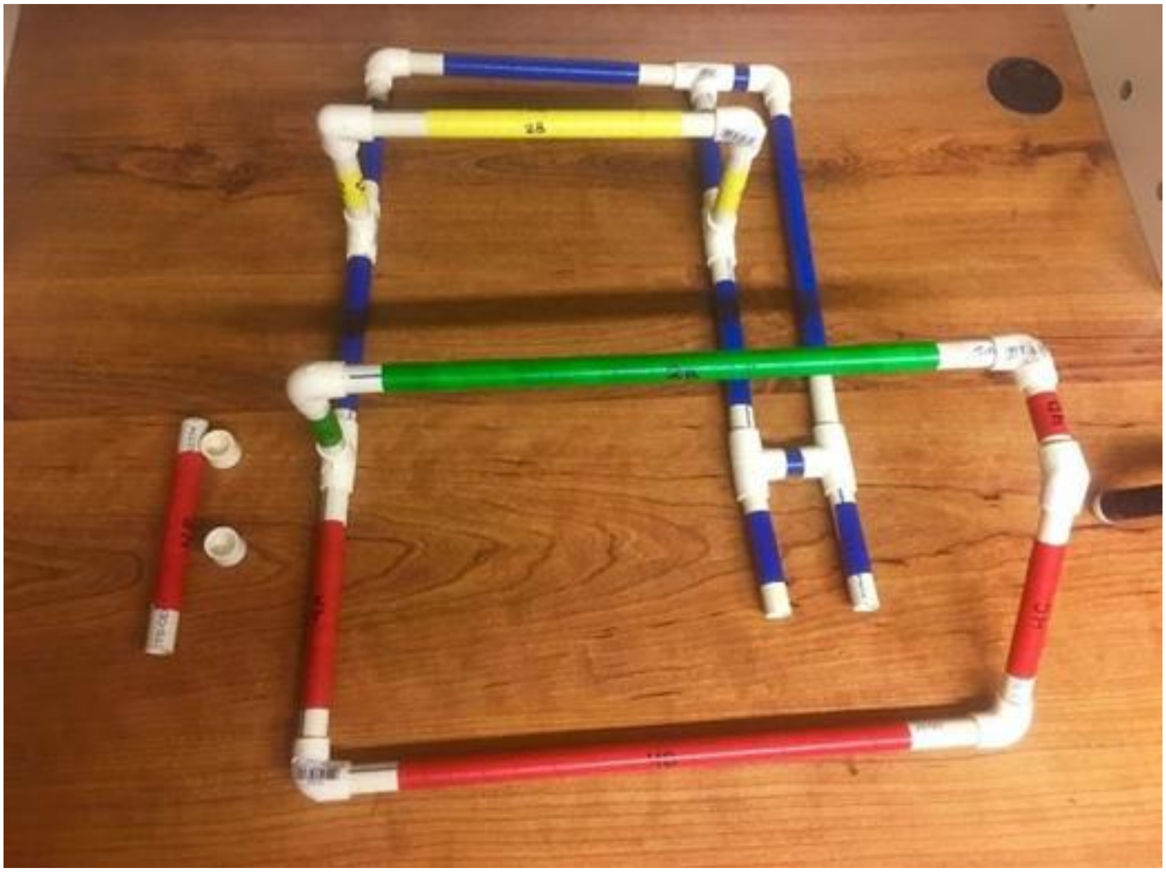

Figure 29. Properly completed pipe assembly.

Half of the participants were given access to a plan sheet with all the info needed to complete the model. This group served as our control group. The other half of the participants served as our experimental group. Members of this group were given access to a plan sheet (like the control group), but they were also given the option to use our AR application that we developed. This application gave the users the ability to view a 3D model of the completed pipe assembly with four different overlays of model-related information. The application also gave these users the option of toggling, "on/off" the different overlays using interactive buttons. The prompt indicated that they would be timed and asked to pay attention to two tasks.

1. Completing the entire model to the best of their ability using the given prompt.

2. And also, to do their best to ensure the entire model was built to plan.

The second request was put in to ensure all participants were given the same opportunity to identify the error we purposely put in the partial assembly. The subjects of this experiment were also informed that they would not be able to speak with the experiment conductor and instructed to ask all questions that they may have before the experiment began. See Figure 30. Below to get an idea of the set-up, those in the AR group would experience.

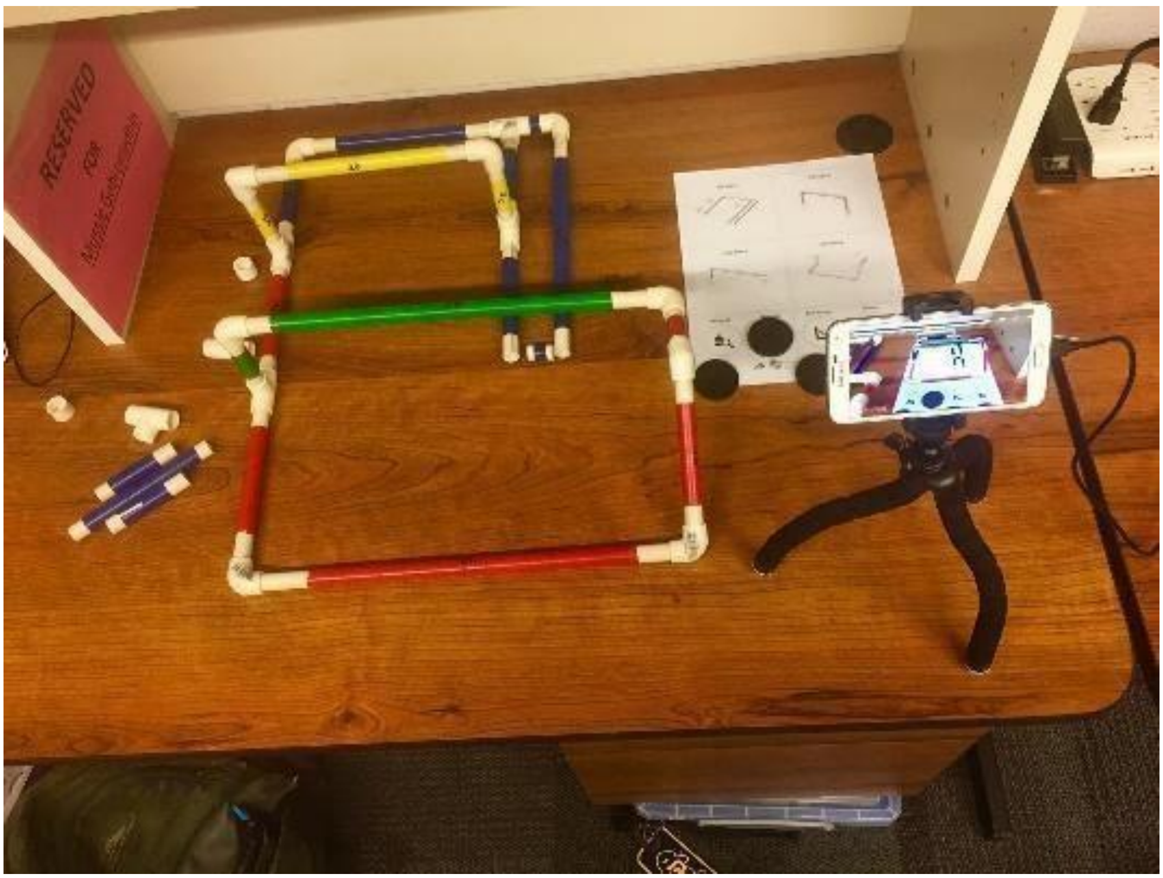

Figure 30. Prototype pipe assembly experiment set-up.

Chapter 4 – Analysis

This chapter will outline the results of the experiments and also provide an analysis of the results. As mentioned, before, the aim was to examine and explore subject behavior when using the AR application to complete the assembly. We measured time to complete the assembly and whether they noticed the purposefully introduced error. We also collected more qualitative data, i.e. what was/ was not helpful when completing the model. This would help us to identify more of the benefits/limitations of using AR and other technologies for such tasks.

4.1 Results

By the end of the testing period we ended up we ended up with a total of fifty-seven participants for this experiment, thirty-two in our control group and twenty-six in our experimental group. We intended on having an equal number of participants in both groups, but technical difficulties with the android device we were initially using resulted in some time where we only had the capacity to test the control group. This resulted in an unbalanced survey.

4.1.1 Completion Time

The fastest completion time recorded was “2:25:00”. The slowest any of our participants took to complete the entire assembly was “17:48:00”. The average time to complete the assembly was “6:32:20”.

4.1.2 Card Rotation Test

The card rotation test included 40 questions and the average score amongst the entire group was between 30 and 31 answers correct out of 40. The lowest score we saw on the card rotation test was 7 out of 40 and the highest score recorded was a perfect 40/40.

4.1.3 Cube Comparison Test

The cube comparison test proved to be more difficult for subjects. This test was scored out of 14 and the average score amongst the entire group was between 8 and 9 answers correct out of 14. The lowest score recorded in the group was 0 out of 14 meaning they were not able to correctly identify whether any of the cubes were similar/different from the initial. You can see a summary of the three metrics discussed above in the table below.

Table 1. Descriptive Statistics "All Participants"

	N	Minimum	Maximum	Mean	Std. Deviation
Compl.Time	57	2:25:00.00	17:48:00.0	6:32:20.00	3:10:10.09
Card Rotation Test /40	54	7	40	30.13	7.929
Cube Comparisons /14	54	0	14	8.70	3.038
Valid N (listwise)	51				

4.2 Checking for Statistical Significance

4.2.1 All Participants

We compiled our data and performed more statistical analysis to learn more and identify significant statistical relationships. You can see in the Table 2. below that the average completion time for the group that did not have access to AR was '6:14' while the average completion time for the members that did have the option to use AR was '6:54'. The average for the entire group was '6:32'. See Table 2. Below.

Table 2. Mean completion times "All Participants".

AR	Mean	N	Std. Deviation
NO	6:14:46.88	32	2:29:33.45
YES	6:54:48.00	25	3:53:34.15
Total	6:32:20.00	57	3:10:10.09

Looking at the data for all participants, there is no statistically significant association between time to complete the assembly and the use of AR. You can see below from the ANOVA table that the data from this experiment generated a “sig” value of .435 (Table 3). Whenever an ANOVA sig value is above .05, we say that there is no statistical significance.

Table 3. ANOVA Table “All Participants”

			F	Sig.
Compl.Time * AR	Between Groups	(Combined)	.617	.435
	Within Groups			
	Total			

a. The grouping variable AR is a string, so the test for linearity cannot be computed.

As mentioned before, all participants in the experiment were required to take two spatial cognition assessment exercises. The data was also looked at to compare participants with varying levels of performance during this exercise. We defined individuals with low spatial cognition as having cube comparison scores below the mean on the cube comparison test and we defined individuals with high spatial cognition as having their cube comparison score above the mean on the cube comparison test.

4.2.2 Low Spatial Cognition

For participants who were identified as having a lower spatial cognition, the average completion time was 6:38. Amongst those that had access to AR the average completion time was 7:50, for those that did not the average time was 6:04. See Table 4. Below.

Table 4. Mean completion times "Low Spatial Cognition"

AR	Mean	N	Std. Deviation
NO	6:04:28.00	15	2:16:33.64
YES	7:50:17.14	7	5:34:47.84
Total	6:38:08.18	22	3:36:48.10

Isolating the data for participants with low spatial cognition, there is no statistically significant association between time to complete the assembly and the use of AR. You can see below from the ANOVA table that the data from this experiment generated a "sig" value of .297 (Table 3). Whenever an ANOVA sig value is above .05, we say that there is no statistical significance.

Table 5. ANOVA Table "Low Spatial Cognition"

			F	Sig.
Compl.Time * AR	Between Groups	(Combined)	1.145	.297
	Within Groups			
	Total			

a. The grouping variable AR is a string, so the test for linearity cannot be computed.

4.2.3 High Spatial Cognition

For participants who were identified as having a lower spatial cognition, the average completion time was 6:43. Amongst those that had access to AR the average completion time was 6:51, for those that did not, the average time was 6:33. See Table 6. Below.

Table 6. Mean completion times "High Spatial Cognition"

AR	Mean	N	Std. Deviation
NO	6:33:00.00	13	3:07:03.21
YES	6:51:15.00	16	3:12:49.59
Total	6:43:04.14	29	3:07:04.90

Isolating the data for participants with high spatial cognition, there is no statistically significant association between time to complete the assembly and the use of AR. You can see below from the ANOVA table that the data from this experiment generated a "sig" value of .799 (Table 3). Whenever an ANOVA sig value is above .05, we say that there is no statistical significance.

Table 7. ANOVA Table "High Spatial Cognition"

			F	Sig.
Compl.Time * AR	Between Groups	(Combined)	.066	.799
	Within Groups			
	Total			

a. The grouping variable AR is a string, so the test for linearity cannot be computed.

4.2 Error Recognition

As mentioned before, the ability to recognize a purposefully introduced error was also observed. The crosstabulation chart in Table 8. below illustrate the results. For the Error results, "No" means the participant was not able to recognize the error, and "Yes" means the participant was successful in recognizing the error. Looking at the crosstabulation, from those in our subject pool that were not given access to AR, 48.3% of participants were able to recognize the error in the partially completed model. From the group that had access to AR, only 21.7% of participants were successful in recognizing the error.

Table 8. Crosstabulation "Error Recognition"

			NO	YES	Total
AR	NO	Count	15	14	29
		% within AR	51.7%	48.3%	100.0%
	YES	Count	18	5	23
		% within AR	78.3%	21.7%	100.0%
Total		Count	33	19	52
		% within AR	63.5%	36.5%	100.0%

There is statistically significant data showing the correlation between the use of AR assistance and failure to recognize the error in the partially completed model. This data is statistically significant because the sig value below on the Chi-Square table is ".048". Like before, whenever a sig value is less than 0.05, we can say that the data is statistically significant.

Table 9. Chi-Squared "Error Recognition"

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.895[a]	1	.048		
Continuity Correction[b]	2.835	1	.092		
Likelihood Ratio	4.018	1	.045		
Fisher's Exact Test				.081	.045
N of Valid Cases	52				

Chapter 5 – Conclusion

In summary, we defined augmented reality and provided a timeline for the development and use of augmented reality and related technologies in the construction and other industries. During our exploration we were only able to yield statistically significant results in regard to the use of AR when recognizing error. We learned that there is statistically significant data showing that having access to AR in our experiments hindered participants ability to recognize error.

The prototype application was developed to provide a proof of concept and for the administration of the experiment. However, the development of the application also forwarded understanding of the capabilities of the technology, while serving as a strong starting point for further exploration and experimentation. To conclude we will explore potential bias that may have been present during the experiment and discuss what would be changed if the experiment were to be administered again.

After looking at the results we feel that there are two bias that could have been present and had an influence. The first one is what is known as "volunteer bias". Volunteer bias is defined as "Participants volunteering to take part in a study intrinsically have different characteristics from the general population of interest" (Catalogue of Bias 2016). We see this more in our experiment because we had only students from the university, and specifically those within the civil engineering and psychology departments to serve as our subject pool. If this were to be done over, it would be interesting to see how the results may differ with a more broad/diverse subject pool.

The second bias we believe could be present is "wrong sample size bias" could have been present and had an effect on the results. When the wrong sample size is used in a study: small sample sizes often lead to chance findings, while large sample sizes are often statistically significant

Along with making changes to address the above bias, if the experiment were to be re-administered, we would like to give the AR group precedent training on using the application. When observing the participants using the AR, we noticed that participants in this group often spent some time trying to familiarize themselves with the application. We believe that this may have also had an impact on the results of experiment and would be curious to see how the results differed with this change.

Bibliography

ARQuake. (n.d.). Retrieved October 19, 2020, from https://www.dutchrosemedia.com/augmented-reality-outdoor/arquake/

Augmented Reality in Healthcare: Top 9 Companies. (2020, March 11). Retrieved October 18, 2020, from https://medicalfuturist.com/top-9-augmented-reality-companies-healthcare/

Chinn, S. (2020, September 17). 7 Uses in 2020 for Augmented Reality in Construction: ESUB Construction. Retrieved November 03, 2020, from https://esub.com/blog/7-uses-in-2020-for-augmented-reality-in-construction/

Donna R. Berryman (2012) Augmented Reality: A Review, Medical Reference Services Quarterly, 31:2, 212-218, DOI: 10.1080/02763869.2012.670604

Ekstrom, R. B., French, J. W., Harman, H. H., and Dermen, D. (1976). Maunal for Kit of Factor-Referenced Cognitive Tests. Educational Testing Service, Princeton, New Jersey.

Emspak, J. (2018, June 01). What is Augmented Reality? Retrieved November 03, 2020, from https://www.livescience.com/34843-augmented-reality.html

Feiner, Steven. (2002). Augmented Reality: A New Way of Seeing. Scientific American. 286. 48-55. 10.1038/scientificamerican0402-48.

HemanthSK, V. (2018, May 25). Augmented Reality. Retrieved October 18, 2020, from https://devopedia.org/augmented-reality

Lohman, D. F. (1979). "Spatial Ability: A Review and Reanalysis of the Correlational Literature (No. TR-8)." Standord University, School of Education.

Morozova, A. (2018, November 26). How Augmented Reality Is Used in the Construction Industry to Save Money and Speed Up Projects. Retrieved November 03, 2020, from https://jasoren.com/augmented-reality-in-construction/

Rabeel. (2020, August 20). Augmented reality Vs QR code. Retrieved October 18, 2020, from https://inaugment.com/augmented-reality-vs-qr-code/

Rieber, L. P. (1995). "A Historical Review of Visualization in Human Cognition." Educational Technology Research and Development, 43(1), 45-56.

Stannard, L. (2020, July 14). HOME. Retrieved October 20, 2020, from https://www.bigrentz.com/blog/augmented-reality-construction

Vaughan-Nichols, S. J. (2009). Augmented Reality: No Longer a Novelty? *Computer, 42*(12), 19-22. doi:10.1109/mc.2009.380

Vuforia Developer Portal |. (n.d.). Retrieved November 03, 2020, from https://developer.vuforia.com/

Zaher, Mohamed & Greenwood, David & Marzouk, Mohamed. (2018). Mobile augmented reality applications for construction projects. Construction Innovation. 18. 152-166. 10.1108/CI-02-2017-0013.