USING AUGMENTED REALITY TO 3D - ENABLE 2D CONSTRUCTION DRAWINGS: AN EDUCATIONAL APPLICATION

By

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Dedicated to my mother, Mrs. Ritu Jain, father, Er. Anil Kumar Jain,
and brother, Er. Prerit Jain

I keep winning because you keep fighting !!!

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GO GATORS!!! JAI SHREE MAHAKAL!!!

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LIST OF ABBREVIATIONS

ABET	Accreditation Board of Engineering and Technology
AEC	Architecture Engineering and Construction
AISC	American Institute of Steel Connection
API	Application Program Interface
AR	Augmented Reality
ASCE	American Society of Civil Engineers
ASEE	American Society of Engineering Education
BIM	Building Information Modelling
CAD	Computed Aided Drafting
CAM-ART	Context-aware Mobile Augmented Reality
CT	Computed Tomography
HMD	Head Mounted Display
HMS	Head Mounted Sight
HUD	Head-up Display
IBM	International Business Machines
IEEE	Institute of Electrical and Electronics Engineers
IRB	Institutional Review Board
MRI	Magnetic Resonance Imaging
PSSUQ	Post-Study System Usability Questionnaire
SDK	Software Development Kit
UF	University of Florida

Abstract of Thesis Presented to the Graduate School
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Requirements for the Degree of Master of Science in Construction Management

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Chair: Masoud Gheisari

Major: Construction Management

In recent years, there has been a rapid expansion of the construction industry. Computation Technology has become an integral part of construction projects. This research examines one such technology called Augmented Reality (AR). AR is the technology which brings virtuality into the real world. AR constitutes between the virtual and the real world by developing an augmented workspace by incorporating the virtual objects into the physical world. The technology is being successfully used in different sectors like Medical Science, Entertainment, Gaming, etc. The paramount goal of this research is to understand if AR can be used in the construction education domain to help students understand construction 2D drawings in a better and more accurate manner. This can be achieved by appending the drawings with the AR technology. To examine this, an experiment was conducted with thirty-four participants (Bachelors, Masters, Ph.D.) from a construction background. The experiment was about comparing 2D drawing of a steel sculpture with the actual built model of that sculpture. The 2D drawing was a little different than actual built sculpture with some errors/mistakes added

intentionally, and the task for the participants was to identify them. The participants were divided into two groups based on the method they used during the experiment. Group 1 was a Paper-based Method and Group 2 was an AR-powered method. The responses of the participants were noted as two variables, that is, the number of correct answers and number of incorrect answers. Participants also answered a Pre-Study Questionnaire and a Post-Study Questionnaire to understand the participants' experience in detail and better way. The results showed that AR can be very effective in increasing the accuracy of understanding of the 2D drawing by eliminating the chances of making errors, and with certain improvements, the technology can become more productive.

CHAPTER 1
INTRODUCTION

1.1 Overview

Traditionally, education has been dependent on lecture based teachings given to students via class notes, text books or on screen projectors. Researchers have been discussing if learning should occur in a mixed environment such that conventional classroom teachings collaborate with the technological learning environment. Despite the emerging technologies being used each day, students are still being trained with traditional, old, and outdated methods of teaching.

Many institutions are interested in accepting new visualization techniques which enhance the current teaching methods *(Liarokapis and Anderson 2010)*. A study in which over 1,400 university instructors participated was conducted at the University of Georgia and Virginia Tech University. It indicated that classroom technologies have a productive effect on instructors' teaching and students' learning. Participants realized that technology has aided them and provided them with enhanced knowledge, and that it presents complex concepts and topics in an improved and an interactive way such that students get more involved in the class activities *(Shirazi and Behzadan 2014)*. In another study, scholars showed that information and communication technology helped in integrating students' knowledge *(Gülbahar 2008)*. Thus, adding a supplementary technological tool with traditional learning methods can be a productive solution in the education field.

One of the main points that must be considered when using a new technology is whether students can perform the same activities with more accuracy and with better understanding as compared to traditional methods of learning. To this end, the major issue is to apply this technology in a proper and powerful way. New generation students are technology friendly and believe in multi-tasking by performing several tasks simultaneously like working on computers, listening to music, and talking on their cell phones.

Recently, many institutions which have been accredited by the Accreditation Board for Engineering and Technology (ABET) have recommended a shift in the teaching approach *(Ayer et al. 2016)*. This shift is mainly due to the realization of above-discussed benefits of alternative education methods. The architecture, engineering, and construction industries have been searching for the latest technologies for classroom education to enhance the efficiency, accuracy, and student-teacher interaction. Augmented Reality (AR) is one of the technologies that can be used to append the 2D drawings with their respective 3D models/views. The technology is developing rapidly and is being used in numerous environments. The technology has been very useful and successful in various sectors like medical science, entertainment, gaming, military and law enforcement, education, etc.

In recent trends, Mobile Augmented Reality is gaining much importance in the construction industry. The ability to learn and understand the interactive information is improved when using a mobile technology, which allows universal and personalized distribution of knowledge *(Lombardi 2007)*. Many handheld devices like smartphones, iPads, iPhones, and tablets enable the users to experience virtual information overlaid on the real-world object, thereby connecting the virtual world and real world. Moreover, mobile devices can gather, store, and operate a large amount of data which makes them suitable for assisting various learning activities in different situations. Other benefits of using mobile devices include their portability, individuality, and social connectivity and interactivity. This research aims to investigate if mobile augmented reality can be used in architecture, engineering, and construction field as an education tool for understanding construction 2D drawings appended with AR technology.

1.2 Construction 2D Drawings

Construction students are still working on 2D drawings to understand any building dimensions, details, and components. Construction 2D drawings serve as fundamentals for any construction project. Also, 2D drawings have become fast and easy to draw but the outcome is still a 2D drawing which does not help in 3D visualization of the building or the structure (Haines Geoff 2015). Recently, engineering design is experiencing a shift from 2D drawings to 3D modeling.

Most projects require 3D drawings and views since it becomes difficult to understand and read 2D drawings completely (Joseph and Perera 2014). Also, 2D drawings do not include all information and knowledge needed to build a 3D product. Further, 2D drawings for large projects become more complex and require more time and attention. This brings more errors in understanding of the drawings. Thus, many companies and institutions have realized that using 3D views along with the 2D drawings can be more efficient and would help in saving time and money. Unlike 2D drawings, 3D modeling is beneficial in the early design stages, and the major difference between the two is 2D drawings are drawn, while buildings are modeled in 3D modeling.

1.3 Problem Statement

Since 2D construction drawings become very complex and make the learning process confusing, it is assumed that 3D model if appended with the 2D drawings can make learning process more autonomous and interactive. It is believed that AR can be a useful asset for this collaboration. The main question of consideration is can AR be used along with 2D drawings to make the construction classroom environment more tech-friendly so that learning process becomes more autonomous and better understandable? Does AR enhance the reading and understanding of 2D drawings? Does it improve the accuracy in interpretation of construction 2D Drawings?

1.4 Objective

This study focuses on application of a mobile digital technology as an interactive cloud-based interface to 3D-enable the 2D drawings to better inspect and review complicated paper-based drawings on the jobsite. The specific objectives of this study are to: (1) use mobile technology and cloud-based augmented reality to better visualize and communicate complicated paper-based construction drawings, and (2) analyze the benefits and simplicity of such platform to enhance users' ability to review paper-based drawings on the jobsite.

1.5 Scope of Research

The primary focus of this research is to give a new dimension to construction classroom education, thus understanding the applicability of AR technology in construction education using mobile devices like iPad, Tablet, etc. Since mobile devices have become very compact, easily available, and used by all, they are perfect hardware tool for the research experiment. The research focuses on 2D drawings appended with the AR technology and understand if it upgrades the quality of understanding the 2D drawings.

1.6 Summary of Proposed Study

Paper-less access to construction blueprints and documents is one of the several advantages that hand-held mobile devices can bring into construction industry (Shen and Jiang 2012; Kim et al. 2015). Although there are several advantages in using such devices, research shows that paper-based construction drawings are still the main sources of information on the construction jobsites mainly because there has not been a reliable tool other than actual paper to provide a communication medium that is low-price and somewhat sustainable on the construction jobsite (Su et al. 2013). Furthermore, construction professionals and workers still want to keep their existing knowledge of 2D design tools, expertise, and skills that they have learned throughout the years and not completely replace them with new BIM-based mobile technologies (Blaton R. 2010). A solution could be allowing the popular paper-based drawings work together and side by side with mobile digital technologies. Our study would focus on using augmented reality technology to 3D-enable the 2D drawings by virtually superimposing the interactive 3D building information models on the 2D paper-based drawings. In such an augmented reality environment, construction professionals on the jobsite can use their hand-held digital devices to experience the power of BIM and better inspect and review their paper-based drawings.

1.7 Importance of Research

Using mobile technology, this case study creates an accessible, and captivating tool that afford both construction professionals and construction students an experiential opportunity to better understand construction drawings and experience how their mobile digital devices on the jobsite can be used as a means of communication. In this study, mobile digital technology is adopted as a platform allowing users to examine virtual 3D models coupled with 2D paper-based drawings that are commonly used on the construction jobsites. Also, knowing that there is a generation of construction professionals that are accustomed to conducting their tasks in traditional paper-based ways, using mobile technologies in a way that is tied to their previous knowledge of paper-based drawings would decrease their resistance to technology & change in general.

CHAPTER 2
LITERATURE REVIEW

2.1 Augmented Reality

Augmented Reality (AR) is the technology which integrates virtual objects with the real world by superimposing Virtuality in a real environment. Azuma properly defines Augmented Reality as a variation of Virtual Reality *(Azuma 1997)*. As Virtual Reality completely involve a user into a virtual environment, one cannot see the real world surrounding him or her. AR allows users to experience the real world with virtual objects superimposed on them. Instead of replacing reality, AR enhances it *(Kaufmann 2003)*.

The very first AR interface had been developed by Sutherland in 1960s *(Zhou et al. 2008)*. In recent years, AR has been gaining a lot of popularity. The same trend has been observed in the research articles reviewed in the research.

2.2 AR Spectrum

2.2.1 Mixed Reality

Mixed Reality is a hybrid reality which produces new environments and visualizations where virtual and real objects co-exist and interact in real time by merging real and virtual objects. The mixed reality spectrum varies between the real environment and the virtual environment as shown in Figure 2-1. A construction domain example of mixed reality spectrum is shown in Figure 2-2. There are four realities in the Mixed Reality (MR) continuum *(Milgram and Kishino 1994)*

1. Real Environment: This is the real world, that is, the physical world.
2. Augmented Reality: In this, digital objects are added to the real world.
3. Augmented Virtuality: In this, real objects are added to the virtual world.
4. Virtual Reality/Virtual Environment: In this, the surrounding environment is completely digital.

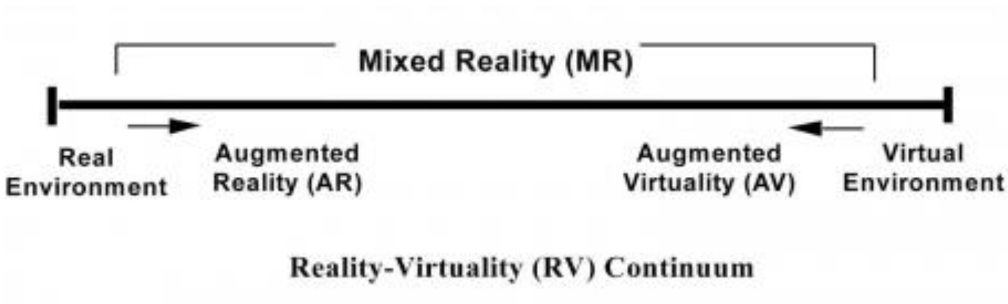


Figure 2-1. Mixed Reality spectrum ranging from reality to virtuality (Photo Courtesy: (Milgram and Kishino 1994)).

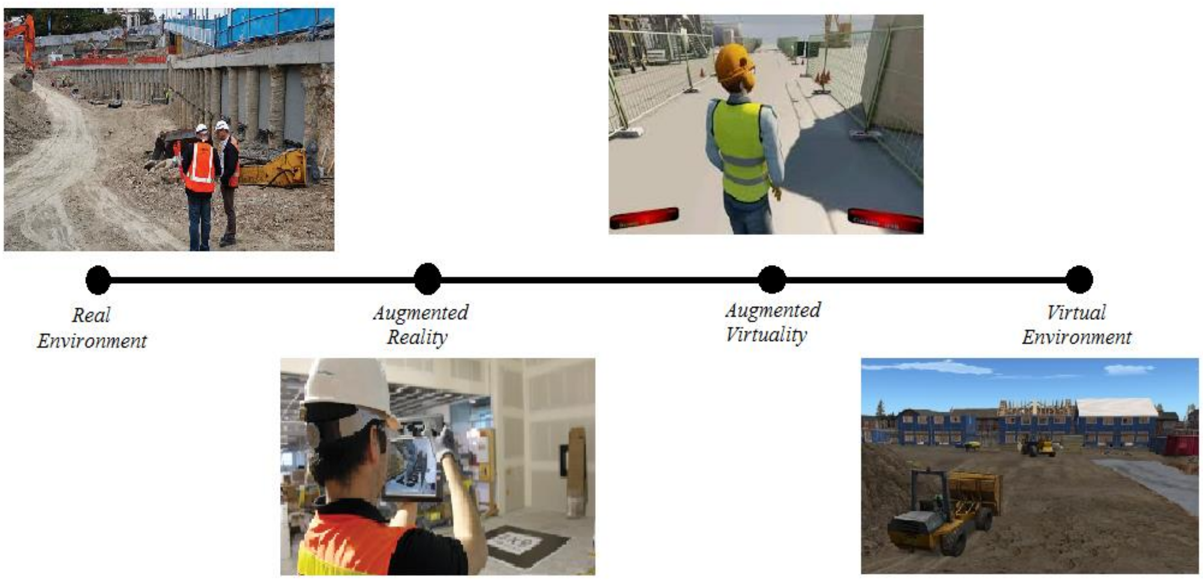


Figure 2-2. Construction site example of Mixed Reality spectrum.

Any variety in the mixed reality continuum requires a hardware device to experience the virtual environment. The hardware devices interact with the developed platform to display and experience the variety of mixed reality. Figure 2-3 presents various examples of interaction devices for the mixed reality spectrum.

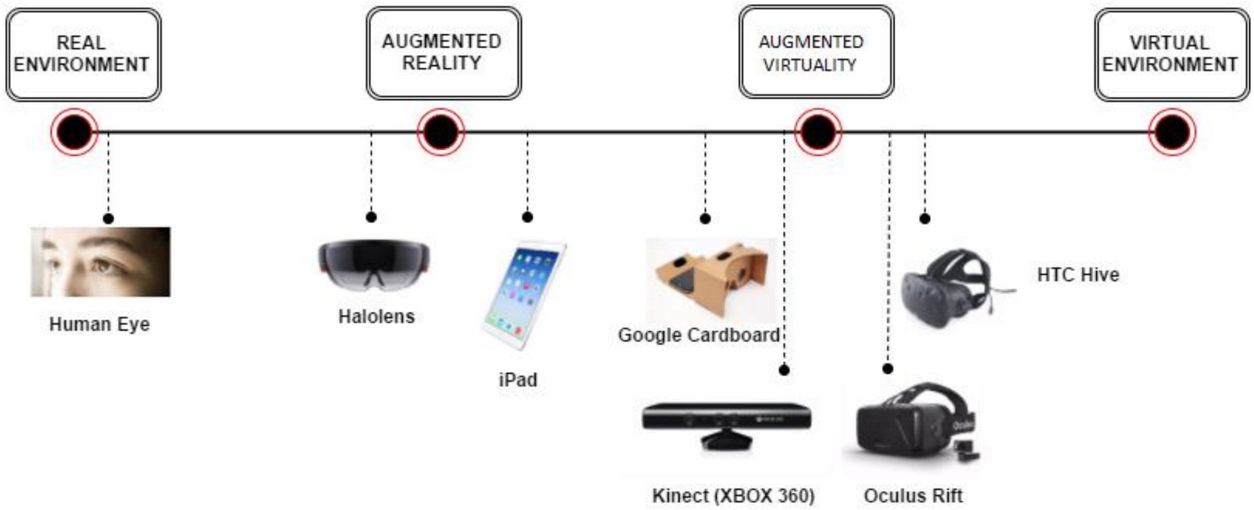


Figure 2-3. Mixed Reality interaction devices.

2.2.2 Comparing Augmented Reality (AR) and Virtual Reality (VR)

Researchers in the construction industry have been exploring on innovating new training methods using Virtual Reality (VR) over last decade. Although VR gives a complete virtual environment which provides unlimited training scenarios, it gives no chance to experience real working conditions (Wang and Dunston 2007).

They share a few similarities, while there are many differences between the two. Figure 2-4 explains their relationship using Venn diagram. Both the technologies are used to enhance and enrich the visualization experience. While AR is a blend of virtual and real world, VR is all about virtual world. AR superimposes the virtual world into the real world, on the other end, VR generates simulation of the real world (McKalin Vamien 2014). AR is usually experienced using hand-held devices like iPad, smartphones, iPhone, etc. VR technology can be experienced by using Head Mounted Displays, handheld devices, etc. AR adds graphic/image/sensation as a new layer, while VR creates all new computer generated reality.

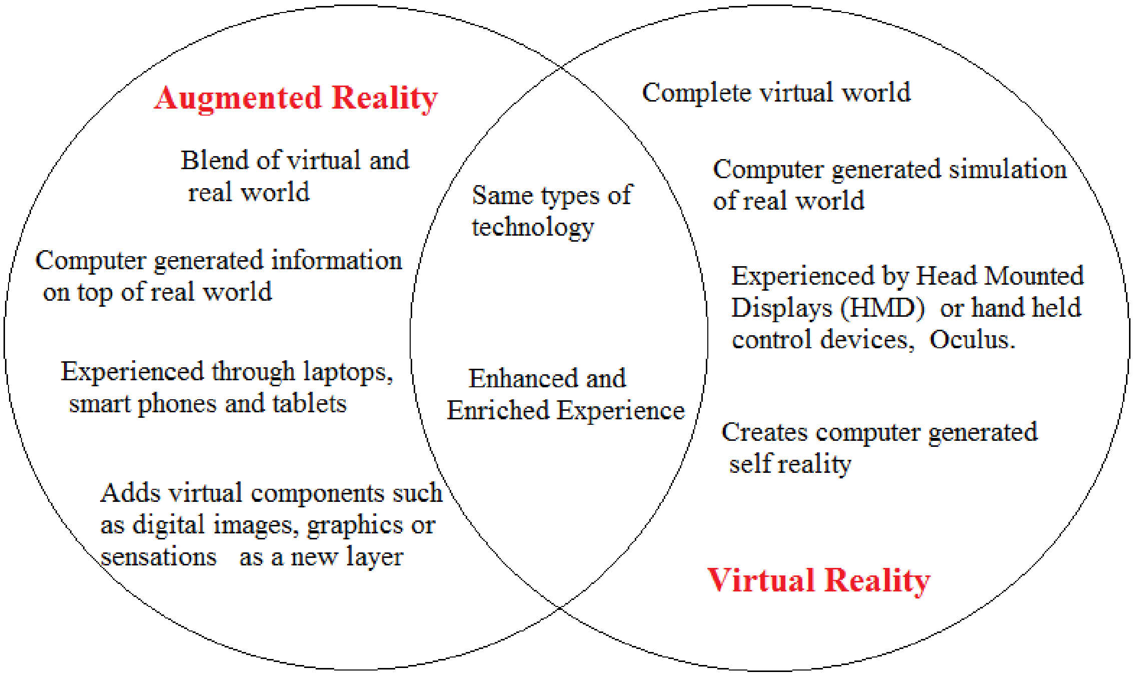


Figure 2-4. Venn Diagram comparing Augmented Reality and Virtual Reality.

2.3 Applications of Augmented Reality

Military and Law Enforcement: The military and law enforcement agencies use AR technology via simulators. Advanced military forces have basic AR goggles. These AR goggles display information such as altitude, light intensity, the angle of sight, enemy location, etc. This information can be calculated on the spot with internal computational power of the goggles since such goggles are not usually designed to use the cloud-based computational power of Internet *(Sood 2012)*. For a long while military aircraft and choppers have been using head-mounted sights (HMS) and head-up displays (HUDs) which overlay virtual graphics over the pilot’s vision of the real world. It provides flight information and basic navigation system *(Perdue 2016)*. By registering the targets, it helps to aim the aircraft’s weapons. Figure 2.5 shows a military augmented reality headset, which provided added visuals, helping in enemy detection, waypoint information, and personnel tracking on the fly.

Figure 2-5. Military Augmented Reality headset (Photo Courtesy: Meghan Young, Baesystems, and device (Meghan 2014)).

Medical Science: AR-enabled surgeries have been increasing rapidly. Such surgeries have less probability of error because of the valuable inputs of computer technology in the surgery. It uses the information for controlling the robots to perform the surgery. A computer gives various alternative methods for the surgery and guides about the method to be used during surgery *(Perdue 2016)*. The AR stream allows remote doctors to view the information of the patient even if the patient is not physically in front of them. Figure 2-6 displays a Surgery Pad, which uses a mobile augmented reality application that allows the doctor to view into the patient and perform the surgery. Per “mbits Imaging GmbH” a channel on YouTube, it was developed at German Cancer Research Center in Heidelberg (2012). It helps in collecting 3D datasets of any patient using sensors like ultrasound imaging, Computed Tomography scans (CT), or Magnetic Resonance Imaging (MRI).

AR might help in training purposes by giving virtual instructions. This could help guide a new surgeon of the required steps, rather than looking from the patient and consulting a manual *(Azuma 1997)*.

Figure 2-6. A Surgery Pad (Photo Courtesy: (mbits imaging GmbH 2012)).

Architecture: AR helps in visualization of building projects. Artificial, computer generated information of any structure in the form of images or models can be superimposed onto the real work site before any construction. AR can help visualization of 2D drawings in animated 3D model (as shown in Figure 2-7). Architecture sight-seeing can be developed via AR applications which allow users to view a building's exterior experiencing virtual model by seeing through its walls, viewing interior objects and layout *(Perdue 2016)*.

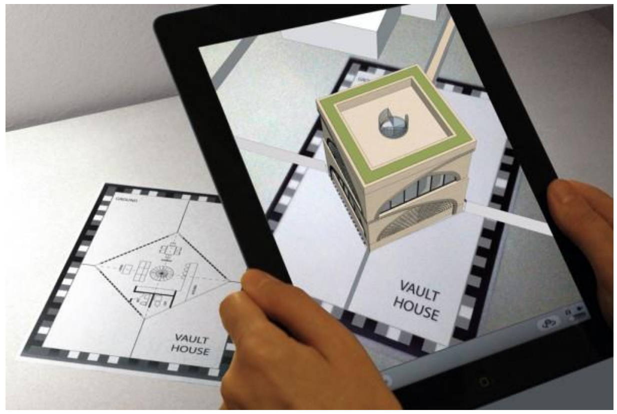


Figure 2-7. Augmented Reality application, superimposing 3D architecture model of a building on a 2D plan (Photo Courtesy: (Rana 2014)).

Entertainment: In several amusement parks around the world, AR technology is being used to make rides such that it is set up in a single hall and gives one a real-world experience of the ride. Secondly, AR helps in merging real actors with the virtual backgrounds. The actor is supposed to stand in front of a blue screen and the scene is recorded by a computer-controlled motion camera. Because the camera location is monitored and the actor’s motions have been recorded, it becomes possible to digitally add the actor into a 3D virtual environment or background *(Azuma 1997)*. This results in lowered production costs since it creating sets which are virtually much cheaper than building all new physical sets *(Perdue 2016)*.

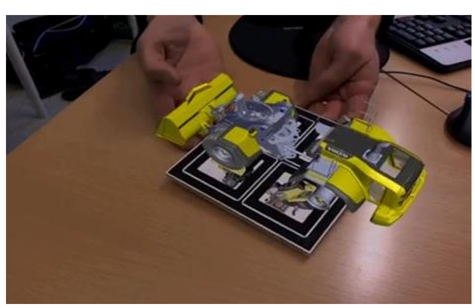


Figure 2-8. 3D-printed augmented reality jigsaw puzzle.

Education: AR technology has been successfully used in various educational institutions as an additional resource other than textbook material or as a virtual, 3D textbook. Usually, head mounts displays are used to experience AR, which allows the students to "relive" events as they are known to have happened, while never leaving their class *(Perdue 2016)*. Figure 2-9 shows AR as a learning tool using an iPad as a display device for visualization of 3D model of a 2D image of an object.

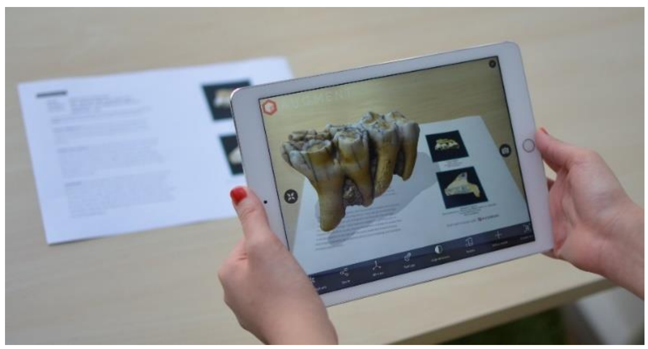


Figure 2-9. Experiencing AR as a learning tool using IPad (Photo Courtesy: Christina, Augment).

2.4 Augmented Reality in Architecture, Engineering, and Construction (AEC)

AR technologies are becoming more mature and established in the professional and educational world. The trend says that AR is getting a very positive response in domains like Education, Design, Architecture, Engineering, Construction, and Entertainment. This reveals AR potential in enhancing existing technologies and working for a better quality of life. These developments are the outcome of the continued development of computer hardware and software. As the AEC industry is shifting increasingly towards digitalization of information, more visualization, and advanced platforms are required for effective use of such information. The main problems in the field of AEC have been miscommunication between workers and professionals at a different level related to project execution, lack of understanding for actual field operators, and variation or alteration between the planned task and implemented the task. By utilizing AR technology, workers can experience and visualize the task and the process which needs to be undertaken. Since AR technologies have that potential to solve these issues, they are well suited in this field.

Recently, AR applications have been growing in the construction sector. DPR Construction uses this technology to show owners of the project how their building will look and function long before its construction *(Forward 2013)*. Using Head-Mounted Display (HMD) as a user interface and display, one can experience 3D walk-throughs of the building in full scale. This ensures that the final plan and looks of a building matches with owner's imagination and expectation. This eliminates design-related change orders and thus help in saving money, time, and resources throughout the project.

Secondly, at DPR Construction, builders use AR in seeing through the walls using QR Code with AR developed an application called BIMAnywhere app (as shown in Figure 2-10). Using this, builders understand and visualize details behind the walls. This helps to minimize rework and saves time.

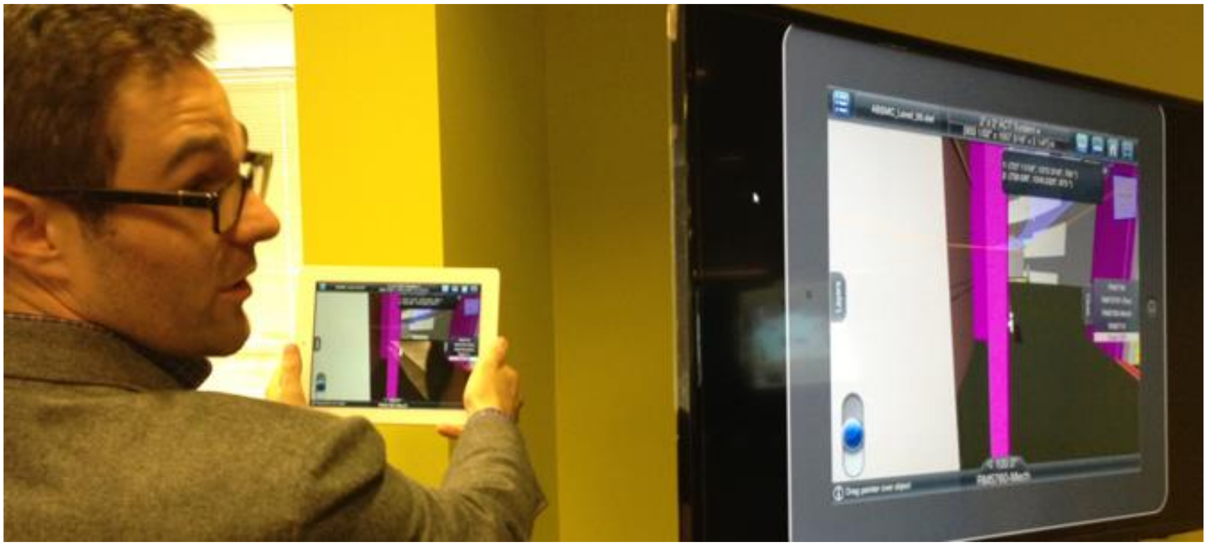


Figure 2-10. Builder Visualizing details behind the wall, using BIMAnywhere app by scanning a QR Code (Photo Courtesy: (Forward 2013))

2.5 Augmented Reality in Architecture, Engineering, and Construction (AEC) Education

Computer technology brings a complete set of tools and application which strengthens the education techniques. Educators are likely to be more interested and encouraged in the teaching process when using these technologies. Also, students are more likely to be motivated in this process *(Fonseca et al. 2014a; Kreijns et al. 2013; Roca and Gagné 2008)*. Researchers have investigated the application of AR in the AEC Education domain. AR is a cost-effective technology which provides students with attractive content and much more interesting with respect to paper books. This technology has been said to be utmost important for focusing the attention of students on actual tasks *(Martín-Gutiérrez et al. 2010)*. The combination of user-machine interaction involving AR with an attractive technology makes students feel more motivated in their studies and understanding *(Sánchez et al. 2012)*.

AR, when coupled with collaboration and interaction, provides multiple affordances in support of technology-based learning *(Shirazi and Behzadan 2013)*. AR makes students more autonomous in learning engineering concepts. This is possible due to assistance by AR technology which avoids the teacher's intervention *(Shirazi and Behzadan 2015)*. In any construction task related discussion on the site, AR reduces the time of decision making. Also, miscommunication during the discussion process gets minimized as compared to the paper-based method of understanding tasks and problems *(Lin et al. 2014)*.

2.6 Literature Review on AR in AEC Education

To achieve the purpose of this research, the author sought to study various research papers from journals and conferences that raised the question as to what is Augmented Reality? What are its applications? How can AR be incorporated into the education environment? Articles between years 1998 to 2016 in the database of the American Society of Civil Engineers (ASCE), Elsevier, Journal of Information Technology in Construction (ITCon), etc., are included in the work. Other sources were Springer, IEEE Database, etc. The author searched with the following keywords: Augmented Reality, Architecture Education, Engineering Education, and Construction Education.

Thus, the author found sixteen articles that were based on the Application of AR in Architecture, Engineering, and Construction Education. Further, certain guiding questions were developed which gave a direction to in-depth reading. Notes were taken in MS Excel Sheet which explained how the questions were answered in papers. The guiding questions were: What was the aim of research? What was the methodology of papers? What platforms and Hardware were chosen in the case studies and experiments? Table 2-1 shows the division of sixteen papers into three different categories, namely, Architecture Education, Engineering Education, and Construction

Education. The table implies that research on construction education has been predominant.

Table 2-1. Number of articles classified by categories of AR application in Education

Category	Number of Articles	References
AR in Architecture Education	3	(Martín-Gutiérrez et al. 2010);(Sanchez et al. 2012), (Fonseca et al. 2013)
AR in Engineering Education	3	(Chen et al. 2011); (Shirazi and Behzadan 2015); (Ayer et al. 2016)
AR in Construction Education	10	(Wang and Dunston 2007); (Behzadan et al. 2011); (Kamat et. al 2011); (Behzadan and Kamat 2012); (Redondo et al. 2013); (Shirazi and Behzadan 2013); (Sánchez et al. 2013); (Mutis and Issa 2015); (Shirazi and Behzadan 2014); (Lin et al. 2015)

Considering AR in the education field as an emerging era, both international and national conferences and leading international journals were considered. Table 2-2 lists the journals and conferences in which the articles were published and/or presented.

Table 2-2. List of journals and conferences of the articles in the field of AR in AEC Education.

Journal [Publisher]	Count	References
Journal of Professional Issues in Engineering Education & Practice [ASCE]	2	(Chen et al. 2011); (Shirazi and Behzadan 2014)
Journal of Computing in Civil Engineering [ASCE]	1	(Lin et. al 2015)
Journal of Architectural Engineering [ASCE]	1	(Ayer et al. 2016)
Computing in Civil and Building Engineering [ASCE]	1	(Mutis and Issa 2014)
Journal of Construction Engineering and Management [ASCE]	1	(Kamat et. al 2011)
Computers in Human Behavior [Elsevier]	1	(Fonseca et al. 2013)
Automation in Construction [Elsevier]	1	(Behzadan and Kamat 2012)
Journal of Information Technology in Construction [ITCon]	1	(Wang and Dunston 2007)
Advances in Information Systems and Technologies [Springer]	1	(Sanchez et al. 2013)
Advances in Engineering Education [American Society for Engineering Education(ASEE)]	1	(Shirazi and Behzadan 2015)

Table 2-2. Continued.

Conference [Publisher]	Count	References
Winter Simulation Conference [Institute of Electrical and Electronics Engineers (IEEE)]	3	(Kamat et. al 2011); (Behzadan et al. 2011); (Shirazi and Behzadan 2013)
International Workshop on User Experience in E-Learning and Augmented Technologies in Education [Association of Computing Machinery (ACM)]	1	(Sanchez et al. 2012)
10th International Conference, Intelligent Tutoring Systems (ITS) [Springer]	1	(Martín-Gutiérrez et al. 2010)
International Conference on Virtual and Augmented Reality in Education [Elsevier]	1	(Redondo et al. 2013)

2.6.1 Previous Research Work

Several researchers have reviewed the literature on AR and its application in the field of Architecture, Engineering, and Construction Education. Researchers have realized the new opportunities of using AR in the teaching and learning environment. Figure 2-8 presents different articles by researchers in the field of AEC Education. It can be understood from the table that primary focus has been in the field of AR in Construction Education.

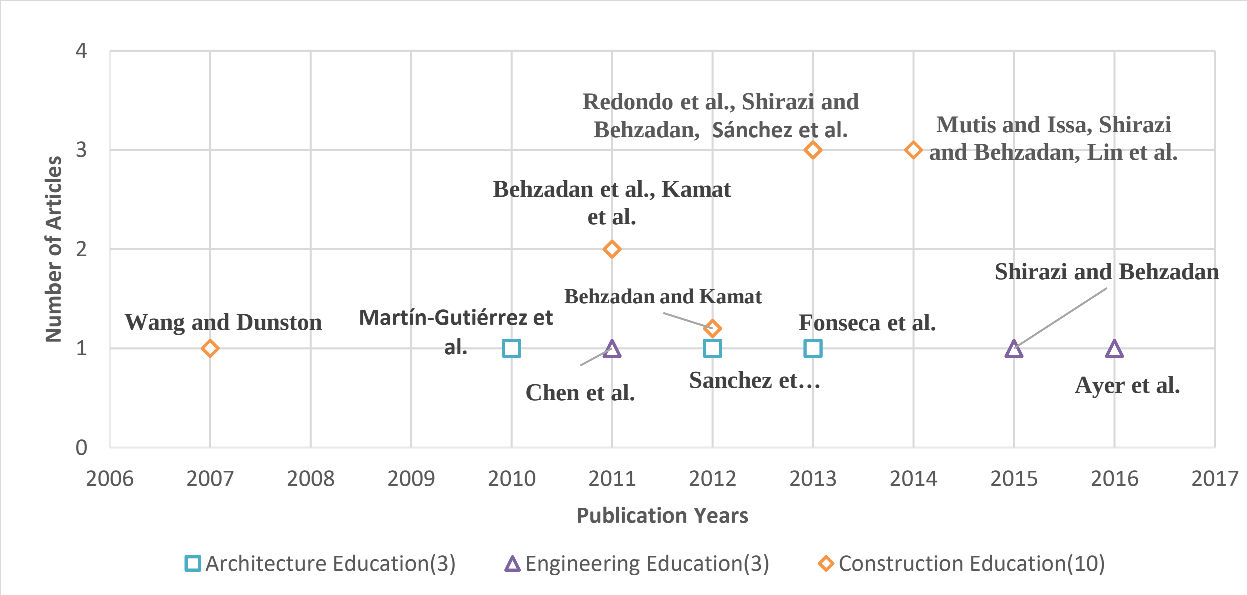


Figure 2-11. Number of “AR in Education” articles with a specific field.

Amir H. Behzadan presented the results of a project with the aim of transforming the present learning scenario in construction by designing and applying an interactive AR tool which would help students understanding the construction process, equipment, and operational safety in a much better way (Behzadan et al. 2011). The AR book was created by combining all sheets of paper with tracker images on them. ARtoolkit was used as a platform which enables viewing of augmented information superimposing over markers with the help of Head mounted displays (HMD). The paper concluded that when properly implemented, AR has a significant impact on student achievement, increasing teacher and student interaction, and developing problem-solving skills of the student.

In other research, Behzadan and Shirazi developed an AR tool called CAM-ART. A Context-aware mobile augmented reality tool (CAM-ART) is an educational tool for the civil engineering and construction industry (Shirazi and Behzadan 2014). The developed AR tool was used in an undergraduate level course for testing and evaluating its impact on and benefits to students' learning. Students were asked to use their handheld devices (i.e. iPad, iPhone, tablets or smartphones) to achieve context-aware virtual information from the course textbook about the material presented in an ordinary way. They formed groups to make the task more interactive and collaborative. Results concluded that AR can help provide a better learning experience and it helps to remove the barrier between technology and students in education. Also, CAM-ART provided an interactive environment and supported interaction and collaboration between students and coursework by indulging participants in a multimedia-enabled learning environment.

In another research project, a study was performed on interventions in Barcelona's Urban Landscape *(Redondo et al. 2013)*. In 2013, Ernest Redondo presented AR to be feasible as a new learning tool. The study was done between two groups S1 and S2. The S1 group performed with traditional methods based on slides and S2 used AR. Results indicated that AR surely helps in understanding architectural proposals. Also, AR encourages spatial relations properly showing real scale and position in real time.

In a similar research, David Fonseca tested the feasibility of AR in mobile devices for Architecture Education *(Fonseca et al. 2014b)*. The research focused on the usability of the tool, improvement in performance of students after the use of AR, and increase in student participation. The study was done with third-year students of an Architecture and Building Engineering degree during the year 2011-2012. A course was designed which was taught in the class and then examined at the end of classes. It can be inferred from the results that AR proved to be useful in case of visualizing simple models but would be less manageable with high-level models. Students felt encouraged with the experience of AR technology and welcomed similar technologies if it improved their academic performances. Students were found more interactive in classroom. They could understand and communicate better with the help of 3D virtual content. Thus, AR maximizes the learning process.

Construction Management students' ability in understanding spatial and temporal constraints on actual job site is hindered due to lack of exposure to construction processes (Mutis and Issa 2014). Understanding the spatial-temporal-constraints problems which occur during the construction phase of the projects will enable students to improve their productivity levels. This was achieved using AR technology. In that study, the experiment used AR to visualize working and access space during the formwork assembly on an infrastructure project (interstate on-ramp). The research demonstrated that the AR technology advocates construction management students by giving them unlimited access to otherwise limited opportunities to participate in jobsite experiences.

Chen et al. conducted a similar research on improving spatial skills of students using AR (Chen et al. 2011). The experiment used AR model and tangible 3D model approaches for developing teaching methods that can improve spatial ability of students in learning concepts of engineering graphics in an optimal way. The research concluded that AR helped in developing interest among students. Both AR and tangible models when used together, can bring better results.

In 2015, a similar research was conducted with the same purpose of identifying Utility of AR as a pedagogical tool for student learning *(Shirazi and Behzadan 2015)*. It used Junaio, an open source web-based programming environment in the experiment to assemble a model building from elementary blocks. The task was performed by two groups: Group 1 used the traditional paper-based method and Group 2 used AR tool. Results with the second group were positive. They looked more autonomous during the task and required less intervention by the teacher. It assured that AR can be used with difficult-to-understand topics and courses.

In 2016, Steven K. Ayer conducted an experiment in his research to redesign a component of an existing building researched AR use in Sustainable Designing education *(Ayer et al. 2016)*. In that experiment, the students designed, visualized, and assessed exterior wall designs to retrofit an existing facility and improve its sustainable performance. An application called ecoCampus was developed along with AR based simulation interface. EcoCampus helped users to visualize possible building design about existing building space. It also assessed in selecting a best possible design for the building. Results concluded that students who used ecoCampus could develop an additional understanding with better overall performance across all disciplines compared with the students who used paper-based formats. One limitation in the research was an internal dependency between AR and simulation game technology. They could not be judged independently.

2.6.2 Platforms/Tools

A software platform is a major part of the software, an operating system or database, or environment under which various programs and applications can be designed to run. These are the software tools which interact with the users via any hardware device. Application software interacts with the operating system and communicates with the hardware device. Various AR tools have been reviewed in research papers and used worldwide in research and development field. Out of 16 research articles taken into consideration, 7 articles used these AR tools, while 5 articles used self-created software platform (Table 2-4) and remaining 4 articles did not involve any software tool in their research. Table 2-3 describes various tools providing Augmented Reality interface. The Table describes the four major tools, their source of access, and references of the articles where they have been previously used as a research instrument to understand and experience AR. Junaio is one of the most versatile and advanced AR browser which provides creator application and Application program interfaces (API’s) for developers.

Table 2-3. Tools in Augmented Reality.

S. No.	Tool	Description	Source	References
1.	ARToolKitPlus Library	Allows easily development of Augmented Reality applications. Most common marker based AR tool.	https://artoolkit.org/	(Chen et al. 2011); (Behzadan et al. 2011)
2.	Unity 3D Game Engine	A customizable, easy to use, a multi-platform development tool.	https://unity3d.com/	(Lin et al. 2014)
3.	Vuforia SDK	Development kit for mobile devices, enables the creation of AR applications using computer vision technology.	https://developer.vuforia.com	(Lin et al. 2014)
4.	Junaio/Metaio	World's most advanced AR browser of mobile. Provides a creator application and API's for developers.	http://officialsite.pp.ua /?p=640353	(Fonseca et al. 2013); (Shirazi and Behzadan 2013, 2014, 2015)

Table 2-4 describes the self-created platform tools used in previous research work. Table shows the Tool name, description and the articles/research it has been used in.

Table 2-4. Self-created AR platform tools.

S No.	Tool	Description	Reference
1.	EcoCampus	EcoCampus uses an augmented reality–based simulation game interface which helps the users in visualizing the possible building design retrofit solutions in the context of an existing space.	(Ayer et al. 2016)
2.	ARVISCOPE	It is a general-purpose 3D visualization environment which has ability of animating simulation models of dynamic engineering operations in outdoor AR	(Behzadan and Kamat 2012)
3.	QCAR	It is an augmented reality SDK (software development kit) with proprietary license developed by Qualcomm Austria Research Center for Android and IOS platforms. It is different from traditional Artoolkit libraries because it allows the use of real images from environment, instead of typical squared markers.	(Sanchez et al. 2012)
4.	Augmented Reality Mobile OpeRation platform (ARMOR)	Augmented Reality Mobile OpeRation platform (ARMOR) evolves from the ARVISCOPE hardware platform. It enhances the design of ARVISCOPE from two aspects, rigidity and ergonomics.	(Kamat et. al 2011)

Table 2-4. Continued.

S No.	Tool	Description	Reference
5.	HUMANAR	It uses computer vision techniques for determining the real camera viewpoint relative to a real-world marker	(Martín-Gutiérrez et al. 2010)

2.6.3 Hardware

Hardware is any physical device which is used as display or output unit. Every software requires at least one hardware to operate. Hardware can be any physical tool, machinery, or equipment which are used in various activities. In AR, hardware can be devices which interact with software programs/platforms or application to act as a display device helping in experiencing AR. Table 2-5 describes hardware devices, their advantage, and the articles which used them. Out of 16 research articles taken into consideration, 13 articles used these Hardware devices, while 1 research used their own created hardware tool called Augmented Reality Mobile OpeRation platform (ARMOR)(Kamat et al. 2010). Remaining two articles were based on case studies which did not involve any experimental hardware tool. The Table shows in the recent years, mobile devices have become more popular as they are compact and more importantly, portable. Also, mobile devices like Tablets, Smartphones, iPads, etc. are cost effective and more convenient as compared to other hardware devices.

Table 2-5. Hardware Devices used in Augmented Reality.

S. No.	Tool	Description	Advantage	References
1.	Head Mounted Display (HMD)	A device used to experience AR. Two components: see-through device and video input. Captures nearby environment and sets it in background view.	User experiences complete 360^0 visual immersions.	(Behzadan and Kamat 2005); (Behzadan 2011, 2012)

Table 2-5. Continued.

2.	Computer	A hardware device which accepts, manipulates, processes the digitalized information and displays the output.	Allows multiple users to visualize and experience AR at the same time. The display screen is relatively larger. Better storage capacity	(Martín-Gutiérrez et al. 2010); (Chen et al. 2011)
3.	Mobile Device	Generally termed as a portable form of computer. Examples: Tablets, Smart phones, iPads, etc.	More convenient as compared to computer desktops. Compact and portable device. Mobile devices are cost effective as compared to computer devices.	(Sanchez et al. 2013); (Fonseca et al. 2013); (Redondo et al. 2013); (Shirazi and Behzadan 2013, 2014, 2015); (Ayer et al. 2016)

2.7 Research Gap

Previous research work shows that surely AR technology has that potential of making learning process interesting, and interactive. But there are a few questions which are still under scrutiny. These are: Can AR be used along with 2D drawings to make the construction classroom environment more tech-friendly and autonomous? Does AR enhance the reading and understanding of 2D drawings? Does AR improve the accuracy in interpretation of construction 2D Drawings?

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Purpose of Study

The purpose of the study is to determine whether AR can be used in a classroom environment as an education tool. The experiment was designed to analyze whether AR helps completing understanding 2D drawing in a better way. Also, does AR increase the accuracy of understanding 2D drawings?

To investigate the proposed study, a between-subjects experiment was conducted. The experimental study was evaluated and approved by the University of Florida's Institutional Review Board (IRB). The IRB approval letter can be found in Appendix A. The researcher had attained IRB-02 training required to conduct the study. The experiment used construction 2D drawings and the mobile AR tool called Augment. Also, the experiment used a mobile device like iPad, smartphone, or tablet. Construction 2D drawings were tested against the same construction drawings powered with the AR tool. An evaluator and an observer were present to measure the time and pen down important events throughout the experiment. Participants were provided with an Informed Consent Form as an agreement to participate in the experiment (Appendix B).

3.2 AR Workflow

The proposed method uses different software applications in a way that users can experience the AR technology independently. Autodesk Revit is used to generate a 3D model using 2D drawings of steel sculpture. Using Inglegreen plugin called OBJ exporter, .RVT file is exported as .OBJ and .MTL file format. Further, the 3D model is published on the web-based mobile AR-application called 'Augment'. Augment is an AR tool which allows users to visualize 3D models virtually on top of 2D trackers in real-time and in customized size and environment. It is a web-based mobile application. The 2D tracker is uploaded on Augment and linked with the respective model. Figure 3-1 shows workflow description of Augment software tool.

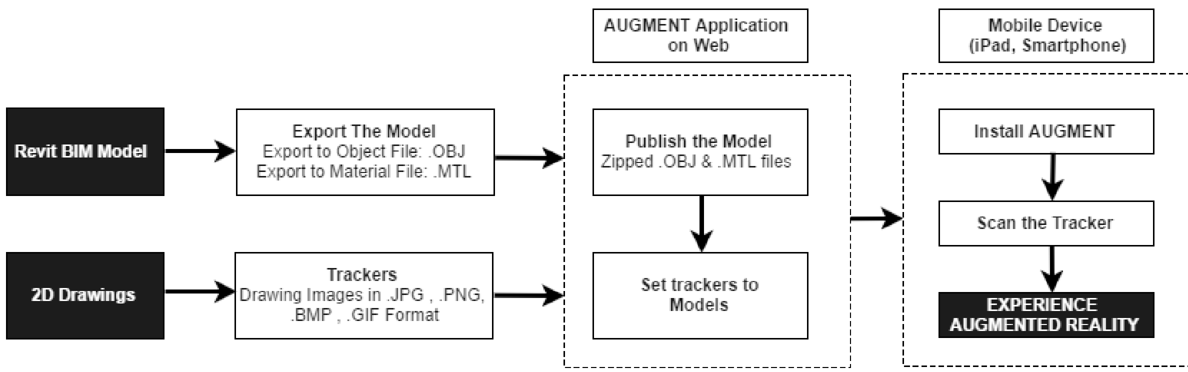


Figure 3-1. Flow chart Representation of AR Work Flow.

3.3 Steel Sculptures

Steel sculptures are structures made of steel framing and steel connections. Steel sculptures are a valuable aid for students to get a better and real visualization of steel framing, components, and their connections.

The original steel sculpture was first erected at the University of Florida's campus in Gainesville on October 29, 1986. It was created by Duane Ellifritt, Ph.D., P.E., Professor Emeritus of Civil Engineering at UF. The sculpture was a full-scale 3D model designed for engineering students with an aim to provide them with up-close, hands-on exposure to steel members and steel connections. A few years later, the American Institute of Steel Connection (AISC) received permission to use and install a scaled-down version of such sculptures all around the United States. Today, there are more than 170 steel sculptures installed in university campuses worldwide *(AISC 2016).*

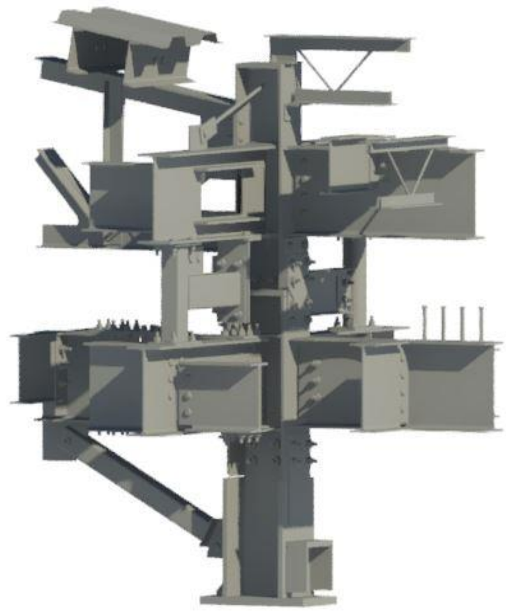
The 2D drawings, elevations, and plans of the steel sculptures can be downloaded from the AISC official website. The researcher read the drawings and observed the drawings to be comprehensive and thus, would serve as a perfect test model.

3.4 Test Location and Participants

The Experiment was conducted at the M.E. Rinker Sr. School of Construction Management, University of Florida. The participants could read and understand 2D drawings of any building or structure. Thus, the experiment was performed in a classroom environment. The steel sculpture built outside the Rinker Hall building was chosen as a test model. Figure 3-2 shows the steel sculpture built at Rinker Hall.

Using Autodesk Revit, 2D drawing, and a 3D model of this steel sculpture were prepared with several changes as compared to the actual model (Constructed Steel Sculpture) which were the primary test element. The experiment was performed on 6th December 2016 in Dr. Masoud Ghiesari's undergraduate class on Graphic Communication in Construction and by other Bachelor's, Master's and Ph.D. students at the Rinker School. There were a total of thirty-four subjects (29 males and 5 females) who participated in the experiment. The participants were divided into two groups, each group comprising of seventeen participants. Each participant completed the task individually.

A) Original Steel Sculpture at Rinker Hall, University of Florida



B) Modelled Steel Sculpture

Figure 3-2. Steel Sculpture at Rinker Hall, University of Florida.

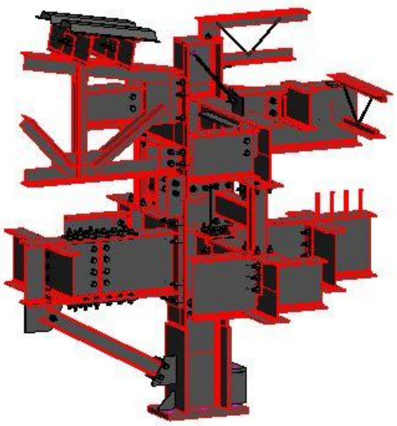
3.5 Test Conditions and Experiment Task

The experiment was conducted between two groups: (1) Participants using the Steel Sculpture's 2D drawings only, that is, a Paper-Based Method and (2) Participants using 2D drawings powered with an AR tool: Augment, that is, AR-powered Method. Participants in both the groups used the actual built Steel Sculpture at Rinker Hall to compare the designed model of that sculpture. In the paper-based method, the participants were provided solely with 2D drawing of the model, whereas in the AR-powered method, participants were provided with the Augment tool using a mobile device like iPad/Tablet along with the 2D drawing.

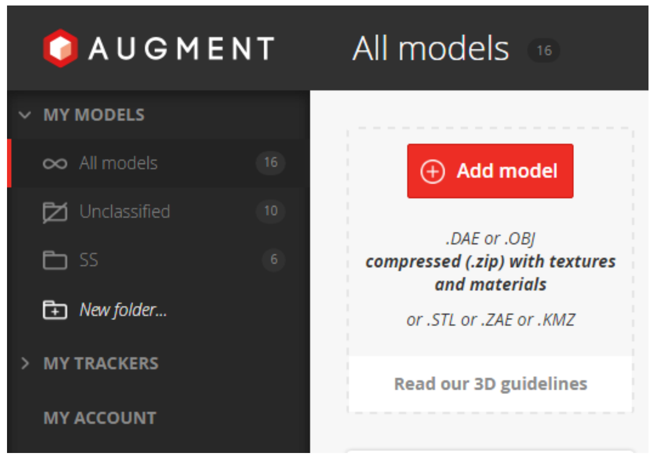
The time duration for completing the task was fixed as four minutes per participant. An evaluator was appointed for measuring the Begin Time and the End

Time for all participants in both groups. An observer was noting down various important events like students' physical movements, facial expressions, body language, verbal comments during the experiment, etc.

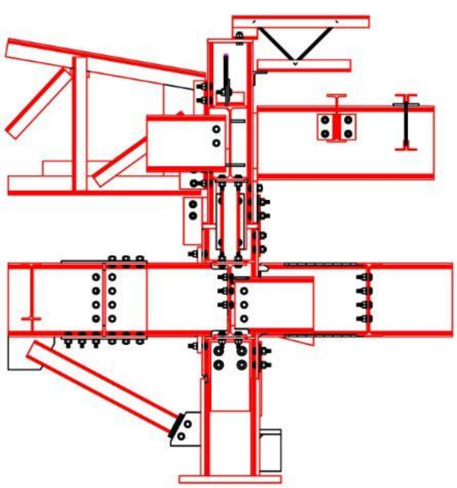
The task was to identify differences between the actual built steel sculpture and Modeled Steel Sculpture. Both the groups compared original building pictures with the resources provided to them. Group (1) performed the paper-based method. They read the drawings of the sculpture and completed the task, while, Group (2) participants used the AR-powered method in which 2D drawing served as a tracker for the AR Model. Figure 3-3 (A to D) shows various steps involved in experiencing AR. Steps (A) and (B) explain the acquirement and publishing of the Revit designed model into the Augment. This was already done in the backhand process, that is, the model was already uploaded and synced with the tracker file; the 2D drawing. In the experiment, the participants performed steps (C) and (D), that is, they used an iPad/Tablet, to scan the tracker and experience the 3D model over the iPad screen. The model was locked on the tracker and scale to be fixed. Within the given time (four minutes), participants observed the 3D model from all angles and the differences between actual sculpture and modeled sculpture were said verbally. Participants were supposed to speak out loud and clear. Their responses were noted by the coordinator of the experiment on a response sheet. Response sheet consisted of the 2D drawing of the model with all the errors marked, and two separate tables for the variables; Correct Answers and Incorrect Answers. If the error/mistake identified by the participant was correct, it was noted in table for correct answers. If the error/mistake identified by the participant was wrong, it was noted in table for incorrect answers. Refer to Appendix E to understand Response sheet in detail.



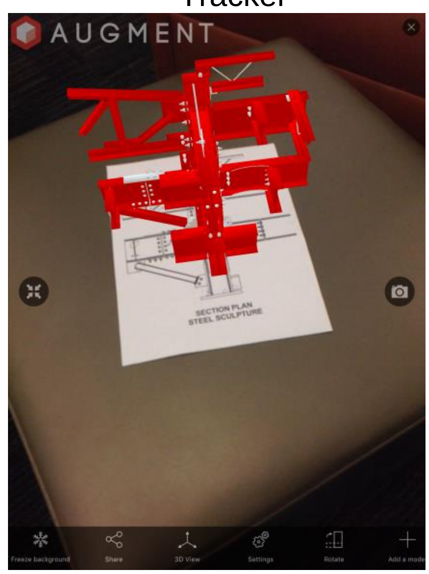
(a) Model Steel Sculpture in Revit



(b) Publish model on Augment and add Tracker



(c) Scan the Tracker Image



(d) Experiencing AR using iPad

Figure 3-3. Steps involved in experiencing AR.

3.6 Data Collection and Analysis

The data collection included a Pre-Study Questionnaire and a Post-Study Questionnaire. In the Pre-Study Questionnaire, participants were required to answer demographic questions, user characteristics questions, and technology analysis questions before the start of the experiment. In demographic questions, participants were asked about their education background, education attainment, and total years of experience in construction industry. In user characteristics questions, they were asked about their age, gender, and visual acuity. Finally, they were asked a few technologies related questions to understand their preferences and previous knowledge about the topic (See Appendix C to understand the Pre-Study Questionnaire in detail). This was helpful in assessing the prerequisite knowledge and interest of the participants in the subject. In Post-Study Questionnaire, a set of seven questions adopted from the IBM Post-Study System Usability Questionnaire (PSSUQ) were used (Lewis 1995; Gheisari et al. 2014). Appendix D gives the complete Post-Study Questionnaire form. The Independent Samples T-test using 95% confidence interval was applied to analyze responses given by students during and after the test experiment. Independent Samples T-test determines whether there is a statistically significant difference between the means in two unrelated groups. Since the means of "Number of Correct Answers" for both the groups were independent to each other and there was no standard mean to compare with, Independent Samples T-test suited best.

The null hypothesis (Ho) and alternative hypothesis (Ha) of the independent samples T test can be expressed in two different but equivalent ways:

Ho: $\mu_1 = \mu_2$ ("the two population means are equal")

Ha: $\mu_1 \neq \mu_2$ ("the two population means are not equal")

OR

Ho: $\mu_1 - \mu_2 = 0$ ("the difference between the two population means is equal to 0")

Ha: $\mu_1 - \mu_2 \neq 0$ ("the difference between the two population means is not 0")

where μ_1 and μ_2 are the population means for group 1 and group 2, respectively.

The t-test looks at the t-statistic, t-distribution and degrees of freedom to determine a p value (probability) that can be used to determine whether the population means differ.

The independent samples T-test was performed using SPSS Statistical Analysis software. The test requires the assumption of homogeneity of variance, that is, both groups have the same variance. SPSS conveniently includes a test for the homogeneity of variance, called Levene's Test, whenever you run an independent samples T test. The hypotheses for Levene’s test are:

Ho: $\sigma_{12} - \sigma_{22} = 0$ ("the population variances of group 1 and 2 are equal")

Ha: $\sigma_{12} - \sigma_{22} \neq 0$ ("the population variances of group 1 and 2 are not equal")

This implies that if we reject the null hypothesis of Levene's Test, it suggests that the variances of the two groups are not equal; i.e., that the homogeneity of variances assumption is violated. The output in the Independent Samples Test table includes two rows: Equal variances assumed and Equal variances not assumed. If Levene’s test indicates that the variances are equal across the two groups (i.e., p-value large), one will rely on the first row of output, Equal variances assumed, while looking at the results for the actual Independent Samples T-Test (under t-test for Equality of Means). If Levene’s test indicates that the variances are not equal across the two groups (i.e., p-value small), one will need to rely on the second row of output, Equal variances not assumed, while looking at the results of the Independent Samples T-Test (under the heading t-test for Equality of Means).

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Statistics for Pre-Study Questionnaire

The participants initially completed the pre-study questionnaire which consisted of a few demographic questions and technological questions. As mentioned earlier, the experiment was conducted with thirty-four participants, out of which 29 were males and 5 females. In terms of their education background, 19 participants were from the construction management background, 1 from architecture, 8 from civil engineering, while 6 others were from both civil engineering and construction management. The number of participants pursuing Bachelors (16) and Masters (17) were almost equal, while one participant obtained a Ph.D. Around 67% (23) of the participants believed their eyesight to be either Excellent or Good, while 33% (11) believed it to be fair or weak. It was found that 92% of the participants agreed that they have previously used handheld devices like Tablet, iPad, etc. Further, 82% of the participants preferred electronic format files (e.g., videos, pdf, jpeg, MS office) over paper format files (e.g., Built-plans, brochures) as tools/resources for the work purpose. Upon investigating the application software preferred by the participants for their work, it was seen that 94% of them preferred 3D Modeling applications (Revit, Sketch-up, 3D-Max, Maya) over 2D CAD software (AutoCAD, Micro Station). Finally, participants were asked technological questions about their previous understanding of BIM and AR. It was found that 25% of the participants had no knowledge about AR while all had at least some knowledge of BIM. Table 4-1 shows the data about pre-study questionnaire in detail.

Table 4-1. Descriptive Statistics for pre-study questionnaire.

Variables		Statistics Number (%) [Total number of participants = 34]
Group Division	Group 1: Paper-Based Method	17 (50%)
	Group 2: AR-Powered Method	17 (50%)
Age	20-23	18 (53%)
	24-27	15 (44%)
	27 above	01 (03%)
Gender	Male	29 (85%)
	Female	05 (15%)
Education Background	Construction Management	19 (56%)
	Civil Engineering	08 (24%)
	Civil Eng./Construction Management	06 (17%)
	Architecture	01 (03%)
Education Attainment	Bachelors	16 (47%)
	Masters	17 (50%)
	Ph.D.	01 (03%)
Visual Acuity (Eye-Sight)	Weak	02 (06%)
	Fair	09 (27%)
	Good	11 (32%)
	Excellent	12 (35%)
Hand-held Tablet, iPad previously used for work purpose.	Yes	32 (94%)
	No	02 (06%)
Tools/Resources Preferred	Paper format files (Built-plans)	06 (18%)
	Electronic format files (pdfs, videos, jpeg)	28 (82%)
Application Software Preferred	2D CAD Application	02 (06%)
	3D Modeling Software	32 (94%)
Previous understanding of BIM	None	00 (0%)
	Some knowledge of	13 (38%)
	Fair	13 (38%)
	Competent	08 (24%)
Previous understanding of AR	None	09 (26%)
	Some knowledge of	14 (42%)
	Fair	09 (26%)
	Competent	02 (06%)

4.2 Statistical Analysis for the Experiment

The data were collected based on two variables; the number of correct answers and the number of incorrect answers. An independent samples t-test was applied to analyze the data using IBM SPSS Statistical Analysis Software. Table 4.2 presents the Means, Standard Deviations (SD), Minimums, and Maximums for the two variables based upon the two groups.

Table 4-2. Descriptive Group Statistics for the Experiment.

Variable		Groups	
		1. Paper Based [N = 17]	2. AR-Powered [N = 17]
Number of Correct Answers	Mean	09.76	08.12
	Standard Deviation (SD)	01.20	01.54
	Minimum	08.00	06.00
	Maximum	12.00	11.00
Number of Incorrect Answers	Mean	04.88	00.18
	Standard Deviation (SD)	02.15	00.39
	Minimum	01.00	00.00
	Maximum	09.00	01.00

On comparing the means of both the groups for the Number of Correct Answers, the mean for the Paper Based group is a little higher than the AR-Powered group. Also, there is a significant difference between the means of two groups for the Number of Incorrect answers. One possible reason for this huge difference was observed during the experiment. While the Paper Based group, participants were just comparing the 2D lines on the drawing with the model instead of visualizing the lines as members and bolts, they were not able to imagine and understand the actual model of the drawing which forced them to make a wild guess multiple times. On the other side, the AR-Powered group participants could visualize and understand the model from which the drawing was provided. Consequently, they could relate the drawing with the model in a better and enhanced way.

To understand the case statistically, the Independent samples t-test was applied using the IBM SPSS Statistical Analysis tool. In this test, the Number of Correct Answers and the Number of Incorrect Answers for both the groups were analyzed. Table 4-3 shows the results of Independent Samples T-test for the first variable, that is, the Number of Correct Answers. A significance level of 5% (α = 0.05) was chosen. The table first shows Levene's Test for Equality of Variance. It gives a F statistic and a significance value (Sig.). The null hypothesis (Ho) for Levene's test says that the variance of the two groups are approximately equal. In other words, that means that the distribution of Correct Answers for the Paper Based group is like the distribution of Correct Answers for the AR-Powered group. The alternate hypothesis (Ha) says that the two distributions are significantly different in shape. It can be seen that Sig. = 0.338 which is much higher than 0.05, thus null hypothesis cannot be rejected and variances are assumed to be equal. For testing for the equality of means, null hypothesis (Ho) says that the means for both the groups can be assumed equal. While the alternate hypothesis (Ha) says that the means are significantly different. The Sig. value corresponding to the t-statistic of 3.483 is 0.001 which is less than $\alpha =$0.05. Thus, alternate hypothesis is accepted and means are considered as significantly different. Lastly, 95% confidence interval gives lower bound and upper bound for mean difference. One can be 95% confident that the actual difference between means of correct answers for both the groups will vary between 0.68383 and 2.61028.

The author discovered possible reasons for this difference between the means. Among many possible reasons, one primary cause could be the learning curve. As observed in the experiment the participants in the AR-Powered group took much more time to understand the technology and its working and to get into the flow, whereas, the Paper Based group participants used the conventional method of reading the drawings and required much less time to begin the task. To improve the learning curve for the AR technology, it is suggested that the technology should be incorporated into the classroom education, giving hands-on exposure to the students in the classroom sessions. The other possible reason could be distraction through the surrounding environment. During the experiment, it was very common to hear comments like “the wind is disturbing”, “the sun is hitting directly into the eyes”, “people moving in the background are disturbing”, etc. Had the experiment been conducted in a more controlled environment, the results would have been different. Indoor and outdoor type of application might also affect this difference.

Further, the Independent Samples T-test was performed for Incorrect Answers. Table 4-4 shows the results of Independent Samples T-test for Incorrect Answers. Like the previous test, Levene’s test was used to determine whether to assume variances of both the groups to be equal or not. In this case, as can be seen in the table that Sig. = .00 which is less than α=0.05. Thus, variances cannot be considered equal and therefore null hypothesis (Ho) is rejected. Further, Sig. for equality of means is also less than α=0.05, thus alternate hypothesis (Ha) is accepted and it is concluded that the means of incorrect answers for both the groups are significantly different. Thus, it can be concluded that AR-Powered group participants performed significantly better than

Table 4-3. Results of Independent Samples T-test for Number of Correct Answers.

		Levene's Test for Equality of Variance		T-test for equality of means						
		F	Sig. (p-value) (α =.05)	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Diff.	
									Lower	Upper
Correct Answers	Equal Variance Assumed	.945	.338	3.483	32	.001	1.64706	.47288	.68383	2.61028
	Equal Variance Not Assumed			3.483	30.233	.002	1.64706	.47288	.68162	2.61250

Table 4-4. Results of Independent Samples T-test for Number of Incorrect Answers.

		Levene's Test for Equality of Variance		T-test for equality of means						
		F	Sig. (p-value) (α =.05)	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Diff.	
									Lower	Upper
Incorrect Answers	Equal Variance Assumed	18.75	.00	8.889	32	.000	4.70588	.52941	3.6275	5.78426
	Equal Variance Not Assumed			8.889	17.07	.000	4.70588	.52941	3.5892	5.82249

Paper based group participants. Therefore, it can be said that AR proves to be better in eliminating the chances of making errors, wild guesses and misunderstanding the 2D drawings.

4.3 Statistical Analysis for the Post-Study Questionnaire

After the completion of the experiment, participants filled out the IBM Post-Study System Usability Questionnaire (PSSUQ). The questions were based on the Likert scale combined with new qualitative variables. The questionnaire had a total of nine questions. The questions requested participants to express their level of agreement with the statements presented using the 7-point Likert Scale provided. Figure 4-1 and Figure 4-2 demonstrate the Likert scale variation for both the groups; Paper based and AR-powered, respectively. The figures list all the questions asked in the post-study questionnaire with the percentage distribution of all the responses on Likert scale (1-7).

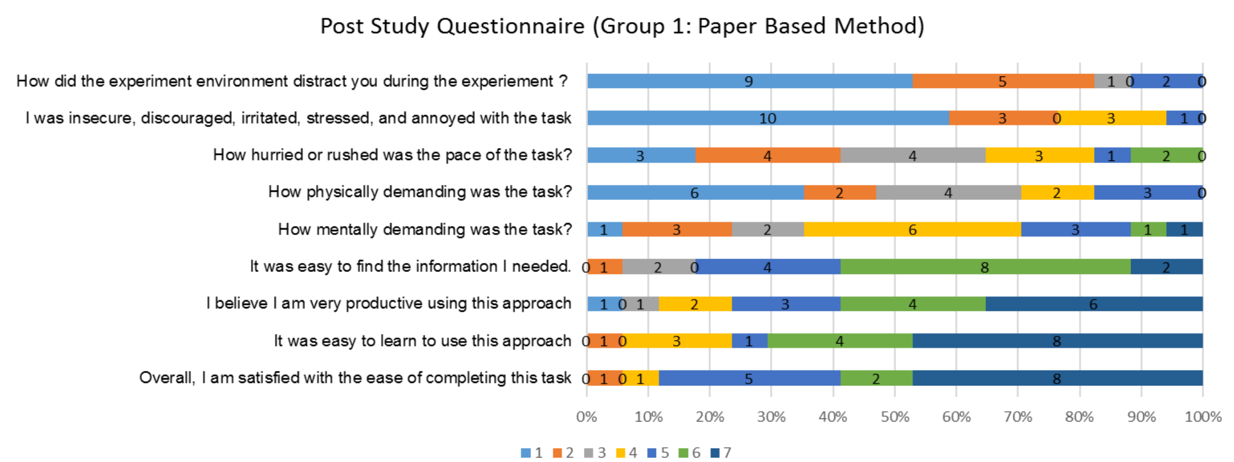


Figure 4-1. 2D bar chart representing percentage distribution of Post-Study Questionnaire for Group 1: Paper Based Method.

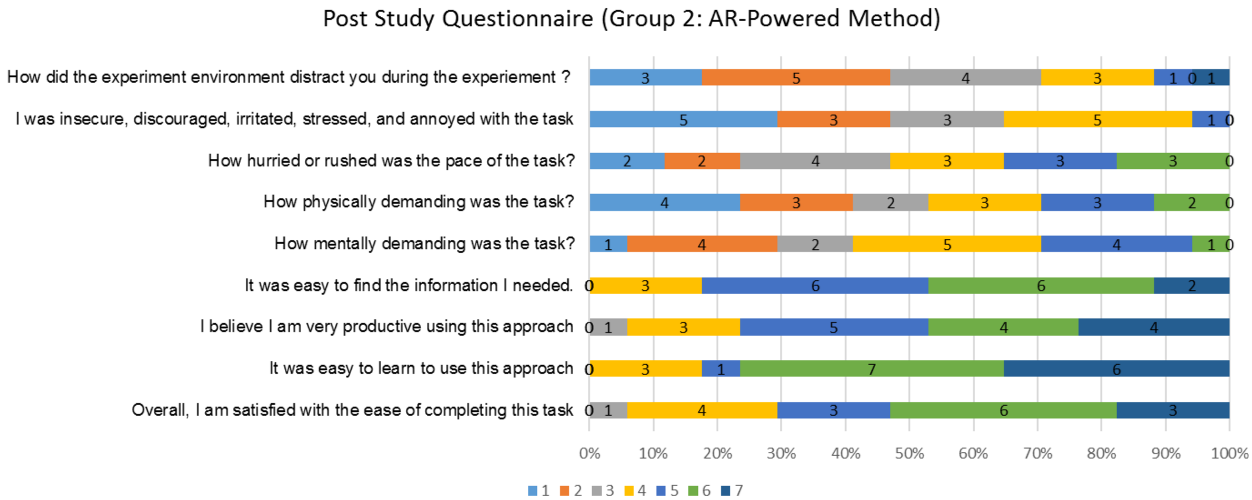


Figure 4-2. 2D bar chart representing percentage distribution of Post-Study Questionnaire for Group 2: AR-Powered Method.

Table 4.5 shows the Means, Standard Deviations (SD), and different Likert scales of all the questions based on the participants' experiment group.

Based on average comparison, participants from the Paper Based group were marginally more satisfied with the ease of completing the task than the AR-Powered group, whereas the mean of ease to learn to use the approach for AR-Powered group is marginally more than the Paper Based group. This difference was observed during the experiment as well. The participants who performed the AR-Powered method looked more excited during the experiment. "WOW", "that is pretty cool", and "cool" were a few comments observed during the experiment. It can also be inferred from Table 4-5 that the AR-Powered group found the task to be marginally less mentally demanding as compared to the Paper Based group, while the same group found the task to be marginally more demanding physically, the reason being that the iPad holding problem and drift problem were observed during the experiment.

Table 4-5. Statistics of the Post-Study questionnaire.

	Questions	Likert Scale	Group (1) Paper Based Method	Group (2) AR-Powered Method		
			Mean (SD)	Mean (SD)	T- statistic	Sig. (a=0.05)
1	Overall, I am satisfied with the ease of completing this task.	1= Strongly Disagree to 7= Strongly Agree	5.82 (1.42)	5.35 (1.22)	1.034	.309
2	It was easy to learn to use this approach.	1= Strongly Disagree to 7= Strongly Agree	5.82 (1.51)	5.94 (1.09)	-.261	.796
3	I believe I am very productive using this approach.	1= Strongly Disagree to 7= Strongly Agree	5.47 (1.7)	5.41 (1.23)	.116	.909
4	It was easy to find the information I needed.	1= Strongly Disagree to 7= Strongly Agree	5.29 (1.4)	5.41 (0.94)	-.287	.776
5	How mentally demanding was the task?	1= Not Demanding to 7= Very Demanding	3.82 (1.55)	3.59 (1.42)	.468	.647
6	How physically demanding was the task?	1= Not Demanding to 7= Very Demanding	2.65 (1.54)	3.24 (1.79)	-1.029	.311
7	How hurried or rushed was the pace of the task?	1= Not Rushed to 7= Very Rushed	3.06 (1.60)	3.71 (1.65)	-1.161	.254
8	I was insecure, discouraged, irritated, stressed, and annoyed with the task.	1= Strongly Disagree to 7= Strongly Agree	1.94 (1.39)	2.65 (1.37)	-1.493	.145
9	How did the experiment environment distract you during the experiment?	1= Not at all Distracted to 7= Extremely Distracted	1.88 (1.32)	2.88 (1.58)	-2.007	.053

It was observed that the participants had a problem in holding the drawing and iPad together. Another major point was observed that the Paper Based group participants picked up the pace very quickly and responded very well in the first half of the time duration (first two minutes). They gradually went slow in the second half of the experiment. While the AR-Powered group participants were comparatively slow in the first half and then picked up the pace in the second. The participants took time to understand the technology and getting hands-on experience. Thus, the AR-Powered group participants found themselves more rushed and hurried during the experiment. One interesting comment which supports this fact was that “It took me time to understand the orientation; I can do much better the second time”. Finally, the AR-Powered group participants were found to be more distracted due to the environment. Comments like “the wind is a problem”, “the paper is flying”, and “the sun is right into my eyes” were observed from the AR-Powered group participants.

On analyzing the data using SPSS, it was found that variances for means of both the groups can be considered equal, that is, similarly distributed. Further, there was no significant difference between the means of both the groups of any of the question. Significance level of 5% was used ($\alpha = 0.05$). As can be seen in Table 4-5, Sig. value for all the questions is greater than $\alpha = 0.05$, which shows that means are approximately equal.

CHAPTER 5
CONCLUSIONS AND FUTURE RECOMMENDATIONS

5.1 Conclusions

Augmented Reality (AR) is a multi-use technology which brings virtuality into the real world. The technology is growing rapidly and is being used successfully in various sectors like Medical Science, Entertainment, Education, Military, etc. This research focused on the AR usage in the field of construction education. The purpose was to examine whether AR can be used to understand the construction 2D drawings in a better and improvised way. The technology was tested on various parameters like accuracy, time, etc. For this, a within-subjects experiment was conducted at the M.E. Rinker School of Construction Management, University of Florida. The experiment was divided into two groups: 1) Paper Based and 2) AR-Powered group. The experiment was based on a 2D drawing of a steel sculpture and thus, participants were chosen from civil engineering, architecture or construction management background. The task was to compare and identify differences between the modified 2D drawing of the steel sculpture model (built across Rinker Hall at the University of Florida) with the actual built sculpture. The responses were noted as two variables: Number of Correct Answers and Number of Incorrect Answers. The participants in both the groups were asked to answer a Pre-Study Questionnaire before performing the experiment and a Post-Study Questionnaire after performing the experiment. Data collected was analyzed by various Statistical tests like Independent Samples T-test using 95% confidence interval, and Levene's test.

The results of the statistical tests showed that the AR surely helps in understanding of 2D drawings in a better way by helping the user in visualizing the actual model of the respective drawing. Thus, the technology helped in appending the 2D drawing by reducing the confusion, and providing a clear vision of the model.

5.2 Limitations

Apart from the ease in understanding the drawings, the technology has a few limitations. The virtual model's drift problem over the tracker (2D drawing) has always been a matter of concern. The technology can be more efficient if the virtual model becomes more stable over the drawing. This can be achieved by adding features like locking the model position, and fixing the scale of the model. Secondly, it was observed that working with a drawing and iPad (or any other mobile device) simultaneously makes the task more demanding physically. It is suggested that if one gets the facility to mark up or make notes on the iPad itself, the method will become tracker-less and the task can be more comfortable to perform.

Also, the experiment conducted in this research involved 34 participants in total i.e. 17 participants in each group. Had there been a larger data set, results could have been different. Another limitation of the research is the pre-requisite knowledge of the participants. Experiment did not consider the participants previous understanding of AR, if any. To keep the experiment unbiased, both paper-based and AR-powered method were performed in alternate order.

5.3 Future Scope

The future recommendations will include development of an application program interface such that it reduces the drift problem and provides the feature to make remarks or notes on the virtual model in the iPad, thus making it a tracker-less approach. This research focused primarily on a complex built steel sculpture drawing plan whose actual built structure was easily available. In future, the technology can be tested with different building plans like Mechanical, Electrical, Plumbing, Structural, or site plan. Hardware devices like AR goggles, or HMDs can be used in future research to make the AR experience more comfortable by making it less demanding physically. This is also help controlling the effect of real environment like wind and sunlight effects. In this research, time duration for the experiment task was fixed to four minutes. In future, variables like time and efficiency can also be taken into consideration to understand about the learning curve and AR performance in a better way.

APPENDIX A
IRB APPROVAL

UF | Institutional Review Board
UNIVERSITY of FLORIDA

Behavioral/Non-Medical Institutional Review Board
FWA00005790

PO Box 112250
Gainesville FL 32611-2250
Telephone: (352) 392−0433
Facsimile: (352) 392−9234
Email: irb2@ufl.edu

DATE: 11/30/2016

TO: Sambhav Jain
2811 SW Archer Road, J-83
Gainesville, Florida 32608

FROM: Ira Fischler, Ph.D., Professor Emeritus
Chair IRB-02

IRB#: IRB201602246

TITLE: Using Augmented Reality to 3D enable the Construction 2D drawings; An Educational Application

Approved as Exempt

You have received IRB approval to conduct the above-listed research project. Approval of this project was granted on 11/29/2016 by IRB-02. This study is approved as exempt because it poses minimal risk and is approved under the following exempt category/categories:

1. This research will be conducted in established or commonly accepted educational settings, involving normal educational practices, such as research on regular and special education instructional strategies, or research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.

2. This research involves the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior. Information obtained is recorded in such a manner that human subjects cannot be identified, directly or through identifiers linked to the subjects. Disclosure of the human subjects responses outside the research does not reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects financial standing, employability, or reputation.

Principal Investigator Responsibilities:

The PI is responsible for the conduct of the study.

- Using currently approved consent form to enroll subjects (if applicable)
- Renewing your study before expiration
- Obtaining approval for revisions before implementation
- Reporting Adverse Events

- Retention of Research Records
- Obtaining approval to conduct research at the VA
- Notifying other parties about this project's approval status

Should the nature of the study change or you need to revise the protocol in any manner please contact this office prior to implementation.

Study Team:

Masoud	**Gheisari**	**Other**

The Foundation for The Gator Nation
An Equal Opportunity Institution
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APPENDIX B
INFORMED CONSENT FORM

Informed Consent

Protocol Title:

Using Augmented Reality to 3D enable the Construction 2D drawings; An Educational Application

Purpose of the research study

The purpose of this research is to study application of Augmented Reality (AR) in a classroom environment as an educational tool.

What you will be asked to do in the study

You will be asked to perform an experiment. The experiment is to compare 2D drawings with an actual constructed model. Also, you will be asked to respond to both a pre-study and post-study online survey of multiple choice and fill in the blank questions.

Time required

15 minutes or less for both the questionnaires and the experiment.

Risks and Benefits

There are no anticipated risks or benefits involved with participating in this survey.

Compensation

There is no compensation for participating in this research.

Confidentiality

Your participation will be anonymous. Your identity will not be revealed.

Voluntary participation

Your participation in this study is completely voluntary. There is no penalty for not participating. Whether you participate or not, it will not affect your grades in any manner.

Right to withdraw from the study

You have the right to withdraw from the study at any time without consequence.

Who to contact if you have questions about the study

Sambhav Jain, Graduate Student, Rinker School of Construction Management, Rinker Hall, University of Florida, phone (352) 870 - 2440.

Dr. Masoud Gheisari, Thesis Committee Chair, Rinker School of Construction Management, Rinker Hall, University of Florida, phone (352) 273-1166.

Who to contact about your rights as a research participant in the study

IRB02 Office
Box 112250
University of Florida
Gainesville, FL 32611-2250
Phone 392-0433.

Agreement

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant: ____________________________________ Date: _________________
Principal Investigator: Sambhav Jain__________________ Date: _________________

.

APPENDIX C
PRE-STUDY QUESTIONNAIRE

Pre-Study Questionnaire

Thank you for participating in the experiment. Before you begin the experiment, please fill this quick survey and let us know your thoughts (your answers will be anonymous).

* Required

1. **Select your Group** *

   - Group 1: Paper-Based Method
   - Group 2: AR-Powered Method

2. **Participant Number** *

Demographic Questions

3. **Total years of experience in Construction** *
   Mention Years in number (Eg: 2 years, 2.5 Years, 2.75 Years)

4. **Educational Background (e.g. Civil Eng.,Building Construction, Architecture)** *
   Check all that apply.

   - [ ] Construction Management
   - [ ] Civil Engineering
   - [ ] Architecture
   - [ ] Other: ____________________

5. **Education Attainment:** *

Mark only one oval.

- High School/Diploma
- Bachelor
- Masters
- Ph.D.
- Other: ....

User Characteristics Questions

6. **Gender** *

- Male
- Female

7. **Age** *

8. **Visual Acuity (eye-sight)** *

Mark only one oval.

- Weak
- Fair
- Good
- Excellent

Technology Analysis

9. **Have you used any handheld tablet computer (e.g. iPad, Nexus, Kindle) either at home or at work?** *

Mark only one oval.

- No
- Yes

10. **Which types of tools/resources do you prefer for work-related tasks?** *

Mark only one oval.

- Paper format files (e.g. brochures, as-built plans)
- Electronic format files (e.g.) videos, PDF, MS Word, MS Excel, MS Access
- Other:

11. **Which type of application softwares would you prefer for work-related tasks?** *
Mark only one oval.

- 2D CAD applications (e.g. AutoCAD, MicroStation)
- 3D Modeling applications (Revit, Sketch up, 3DSMax, Maya)
- Other: ____________________

12. **Rate your understanding of Building Information Modeling (BIM)** *

- None
- Some knowledge of
- Fair
- Competent

13. **Rate your understanding of Augmented Reality** *
Mark only one oval.

- None
- Some knowledge of
- Fair
- Competent

APPENDIX D
POST-STUDY QUESTIONNAIRE

The Post Study System Usability Questionnaire (PSSUQ)

Thank you for participating in the Experiment.
Please fill this quick survey and let us know your thoughts (your answers will be anonymous).

*** Required**

1. **Select your Group ***
   Mark only one oval.

   - ( ) **Group 1: Paper-Based Method**
   - ( ) **Group 2: AR-Powered Method**

2. **Participant Number ***

   ____

3. **Overall, I am satisfied with the ease of completing this task ***
   Mark only one oval.

	1	2	3	4	5	6	7	
Strongly Disagree	( )	( )	( )	( )	( )	( )	( )	Strongly Agree

Any Comments?

____

4. **It was easy to learn to use this approach ***
   Mark only one oval.

	1	2	3	4	5	6	7	
Strongly Disagree	( )	( )	( )	( )	( )	( )	( )	Strongly Agree

Any Comments?

____

5. **I believe I am very productive using this approach ***
   Mark only one oval.

	1	2	3	4	5	6	7	
Strongly Disagree	( )	( )	( )	( )	( )	( )	( )	Strongly Agree

Any Comments?

____

6. It was easy to find the information I needed. *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Agree

Any Comments?

---

7. How mentally demanding was the task? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not Demanding	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Demanding

Any Comments?

---

8. How physically demanding was the task? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not Demanding	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Demanding

Any Comments?

---

9. How hurried or rushed was the pace of the task? *
Mark only one oval.

	1	2	3	4	5	6	7	
Not Rushed	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Very Rushed

Any Comments?

---

10. I was insecure, discouraged, irritated, stressed, and annoyed with the task *
Mark only one oval.

	1	2	3	4	5	6	7	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Strongly Agree

Any Comments?

---

11. **How did the experiment environment distract you during the experiment? ***
Mark only one oval.

	1	2	3	4	5	6	7	
Not Distracted	◯	◯	◯	◯	◯	◯	◯	**Very Distracted**

Any Comments?

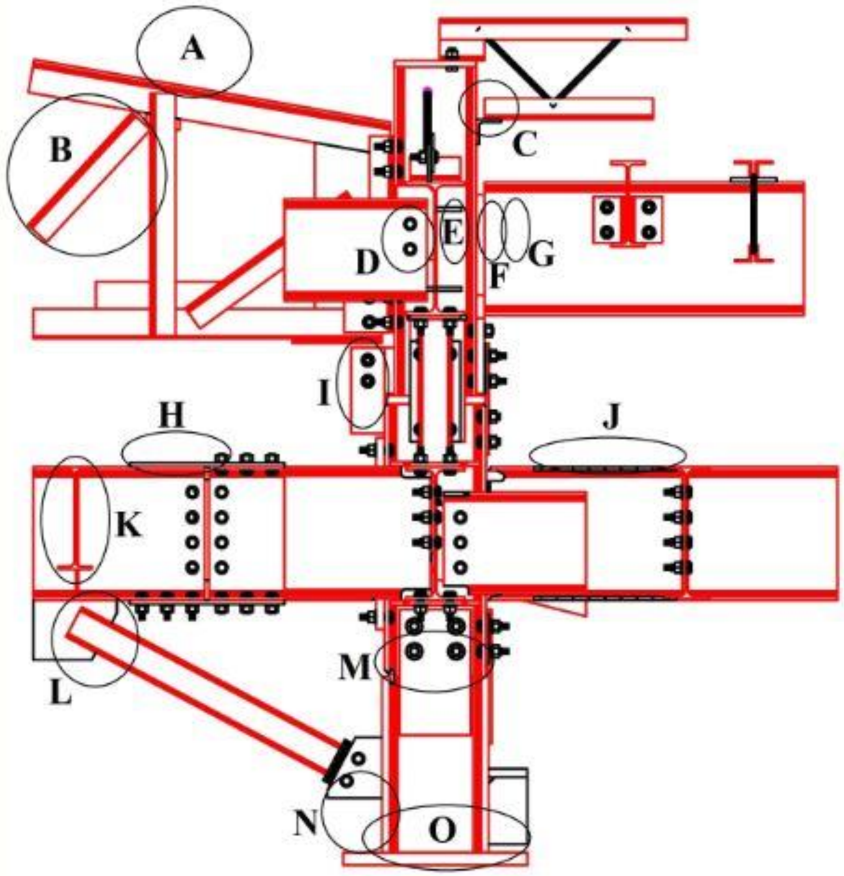
____

Any other comments and suggestions?

____

____

APPENDIX E
RESPONSE SHEET



RESPONSE SHEET

Group Number:

Participant Number:

CORRECT ANSWERS		INCORRECT ANSWERS	
1	11	1	11
2	12	2	12
3	13	3	13
4	14	4	14
5	15	5	15
6		6	16
7		7	17
8		8	18
9		9	19
10		10	20

Total Number of Correct Answers:

Total Number of Incorrect Answers:

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BIOGRAPHICAL SKETCH

Sambhav is a researcher who shares interests in integrating BIM and AR to create mixed reality platforms for construction education applications. He is a graduate student at the M.E. Rinker Sr. School of Construction Management at the University of Florida. He received his B.Sc. in Civil Engineering from SVITS, Indore, India (2015). Expected Graduation: Spring 2017

In future, Sambhav aims to do his duties for the society by building a few schools where poor children can be provided with the primary education for free. He aims to dedicate his life to his family and to the people who are deprived and impoverished. "No success is well cherished if there are no celebrators to celebrate with."

- Sambhav Jain

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